NASA Contractor Report 195392

IN-71
39655
42P

Active Control of Fan Noise-Feasibility Study

Volume 1: Flyover System Noise Studies

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(NASA-CR-195392-Vol-1) ACTIVE CONTROL OF FAN NOISE-FEASIBILITY STUDY. VOLUME 1: FLYOVER SYSTEM NOISE STUDIES Final Report (GE) 42 p

N95-21888

Unclas

G3/71 0039655

October 1994

Prepared for
Lewis Research Center
Under Contract NAS3-26617 Task Order 5

National Aeronautics and
Space Administration

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Nomenclature

AFN............... Designation for airframe noise component
ANC.............. Active Noise Control
APP............... Approach
BPF............... Blade-Passing Frequency
2BPF............. Second harmonic of Blade Passing Frequency (Twice BPF)
3BPF............. Third harmonic of Blade Passing Frequency (Three times BPF)
BPR............... By-Pass Ratio
C/B................ Cutback
CNJ............... Designation for jet exhaust noise component
COM............. Designation for combustor noise component
dB.................. decibel
DOC.............. Direct Operating Cost
E^3.................. Energy Efficient Engine
EPNL............. Effective Perceived Noise Level
FAST............. GEAE aircraft flyover system noise prediction program
FEX............... Designation for fan exhaust noise component
FIN................ Designation for fan inlet noise component
FPR............... Fan Pressure Ratio
GEAE............ General Electric Aircraft Engines
H/T................ Hub-to-Tip radius ratio
NASA............ National Aeronautics and Space Administration
OPR............... Overall engine Pressure Ratio
PNdB............. Perceived Noise decibels
PNL............... Perceived Noise Level
PZT............... Lead Zirconium Titanate piezoceramic material
QCSEE.......... Quiet Clean Short Haul Experimental Engine
S/L................. Sideline
SPL................ Sound Pressure Level
T_{41max}......... Combustor exit temperature
T/O................ Takeoff
UBE.............. Ultrahigh-Bypass Engine
W2................. Fan weight flow
%ΔFB............ Percent Change in Fuel Burn
%ΔMFGC Percent Change in Manufacturing Cost
%ΔMTC Percent Change in Maintenance Cost

Active Control of Fan Noise - Feasibility Study
Volume 1: Flyover System Noise Studies

1. Introduction

The advent of ultra-high-bypass engines with thin, short outer nacelle structures will at the same time increase the importance of tones as contributors to the radiated noise levels and make it more difficult to provide adequate passive acoustic treatment for their suppression. One possible means of overcoming this problem is the application of the principles of Active Noise Control (ANC), such that an array of electrically-driven secondary noise sources mounted on the fan inlet or exhaust duct walls are used to generate sound waves that physically cancel out the waves from the primary aeroacoustic fan source.

The primary objective of this study was to assess the feasibility of using wall-mounted secondary sources, in terms of both their ability to generate sufficient acoustic energy with practical weight and power restrictions, and their ability to couple with fan duct acoustic modes such that the far-field radiation is significantly reduced over a wide area. An aircraft flyover noise system study was conducted to determine the potential benefit that could be achieved by ANC suppression of dominant tones, assuming the concept can be physically realized. A design concept and prototype for a light-weight, high-power ANC transducer was developed based on the use of new piezoceramic materials, since such a transducer will be critical to the eventual success of the method.

Volume 1. of this report presents the results of the system noise studies to evaluate the potential impact of active noise control. Volume 2 presents the results of the transducer element design.

2. Summary

A study has been completed to examine the potential reduction of aircraft flyover noise by the method of active noise control (ANC). It is assumed that the ANC system will be designed such that it cancels discrete tones radiating from the engine fan inlet or fan exhaust duct. Thus, without considering the engineering details of the ANC system design, tone levels are arbitrarily removed from the engine component noise spectrum and the flyover noise EPNL levels are compared with and without the presence of tones. The study was conducted for a range of engine cycles, corresponding to fan pressure ratios from 1.3 to 1.75. The major conclusions drawn are that, for a fan pressure ratio of 1.75, ANC of tones gives about the same suppression as acoustic treatment without ANC. For a fan pressure ratio of 1.45, ANC appears to offer less effectiveness than passive treatment. Additionally, the unexpected result was obtained that ANC appears to be more effective at sideline and cutback conditions than at approach. Overall EPNL suppressions due to tone removal range from about 1 to 3 dB at takeoff engine speeds and from 1 to 1.5 dB at approach speeds. Studies of economic impact of the installation of an ANC system for the four engine cases indicate increases of DOC ranging from 1% to 2%, favoring the lower fan pressure ratio engines. Further study is needed to confirm the results by examining additional engine data, particularly at low fan pressure ratios, and to study the details of the current results to obtain a more complete understanding. Future studies should also include determining the effects of combining passive and active treatment.

3. Background and Program Objectives

3.1. Active Noise Control of Aircraft Engines

In its simplest form, the concept of active noise control can be considered as the provision of a secondary noise source that is located and controlled such that it radiates sound waves that interfere destructively with those generated by the primary sound source, for which noise suppression is desired. The sound suppression may occur over only a limited region of space, depending on the complexity of the sound field being controlled. The reader is referred to several papers that address the general concept of active noise control.[1,2]

In the complex sound field of an aircraft engine duct, the simple concept of sound wave destructive interference may not be the only mechanism by which active noise control can suppress noise. Other possible mechanisms are the absorption of sound by the control transducers and the reflection of sound waves due to duct wave impedance changes created by the control sources (a coupling effect between active sources and aeroacoustic sources). Each of these mechanisms may operate or dominate under certain operating conditions or frequency regimes, and it is important to know which mechanisms are important for the case being considered.

Given a properly positioned error signal microphone and adequate sound output power of the ANC transducers, it has been demonstrated that active noise suppression can be obtained over a limited region of space using systems designed with very little understanding of the physics of the noise generation and propagation process. The algorithms built into the ANC signal processing control systems will adjust the ANC loudspeaker outputs until the signal received at the error microphone is minimized.

In the case of radiation from an aircraft engine duct, however, it is impractical to position error microphones at the locations where it is desired to minimize the sound, on the ground beneath an aircraft flying its approach or takeoff flight profile. Given the complexity of the sound field in, and radiating from, the duct, it is questionable whether an error microphone located within the inlet or on the airplane will be effective, although this is a subject of current research. A more detailed understanding of the propagation phenomena for both the primary and the ANC sources is necessary to overcome this problem.

If the ANC source can be used to cancel the offending primary source mode(s) before they radiate from the duct, noise suppression will be achieved at all radiation angles. To do this in an optimum fashion, it is necessary to know how many ANC transducers are needed and where they should be located.

The concept of using active control to reduce duct noise has known for many years, well before the development of the electronic control systems that made it practical. Lueg filed for some of the original patents for noise cancellation using an active feedback circuit in a duct.[3] Swinbanks[4] presents one of the earliest theoretical developments of the application of active noise control using wall-mounted sources in rectangular and circular ducts. Although limited to the plane wave propagation case, Swinbank's study includes the effect of Mach number and the use of sources at two planes to provide active radiation in one direction only. Swinbanks suggests the design of an electronic control system, but the study is slightly before its time.

Ford[5] includes the effect of the backward traveling wave generated at the control plane and re-reflected at the source plane to form a standing wave, thus effectively coupling primary and control sources. Ford re-invents the two-plane uni-directional control source (without reference to Swinbanks!). Additionally, Ford concludes that horns may not be a particularly effective means for coupling loudspeakers to ducts due to complications that arise from phase shifts, the fact that the horn will be tuned to a narrow frequency band, and coupling of the horn to the duct field, and recommends near direct coupling of the loudspeaker to the duct port.

Zander and Hansen[6] discuss the postulates for the different energy mechanisms that may apply to active noise control in a duct. They consider the control of higher order modes in rectangular ducts but for relatively specific configurations of duct and source geometry. They note the particular lack of success in prior reduction of higher order modes in ducts.

Eriksson, Allie, Hoops, and Warner[7] describe the design of an adaptive control system that was demonstrated to be successful in suppressing lower order modes in a duct. The system requires no knowledge of the duct propagation, and is based on the principle that the number of feedback sensors and ANC transducers must essentially be equal to the highest mode order to be reduced. Thus, a mode that has two positive and two negative regions would require a four channel system.

Silcox and Elliott[8] demonstrate the control of higher-order random noise modes using a single input/multiple output feedforward control system. This system required three sensor elements (one feedforward sensor and two error sensors) and two ANC transducers to control the two lowest order propagating modes, up to the cut-on frequency of the third mode. Suppression levels on the order of 20 dB overall were experimentally obtained over a broadband frequency range below the third mode cut-on frequency.

Stell and Bernhard[9,10] present a complete analysis of the modal propagation in ducts where the primary source is mounted on an otherwise rigid termination at one end of the duct. They examine the optimum placement of the control sources and the coupling effects of evanescent modes. They confirm that noise in a duct with N propagating modes can be controlled with N control actuators, but indicate that the multi-mode controller will be more complex, requiring means of mode discrimination. They demonstrate that in trying to control a small contribution from an evanescent mode, the controller will allow a "leakage" of propagating mode energy through the duct while minimizing the control signal.

Thomas, Burdisso, Fuller, and O'Brien[11] have instrumented a JT15D turbofan engine with loudspeakers and developed a three channel active control system with which they have demonstrated active noise suppression in the farfield of an aircraft engine. This system uses an error sensor located in the farfield, and produces suppression of up to 16 dB over a 60 degree angle. They have demonstrated simultaneous control of multiple tones.

Thomas, Burdisso, Fuller, and O'Brien have clearly demonstrated that it is possible to generate sufficient acoustic energy to cancel energy radiated by a turbofan engine. Their demonstration was, however, limited to lower order modes and required an error sensor located in the farfield. Further effort is needed to extend the method to higher order duct modes and to develop an on-board error sensor system. Stell and Bernhard point out that the higher order mode case will require a more complex system, with number of channels equal at least to the number of modes that are propagating. Although many difficulties remain to be overcome, nothing yet has indicated that ANC of aircraft engine noise is an impossible task.

3.2. Overall Program Objectives

The objective of this study was to establish the feasibility of and to identify the technology barriers to actively controlling fan noise by introducing "anti-sound" into the fan ducts, for application to high bypass ratio aircraft engines. The results of this study can provide the foundations for decisions about the advisability and direction of further effort directed toward the eventual demonstration of active suppression of noise in flight on an aircraft.

First, a system study was conducted in which aircraft flyover noise was predicted with the radiated tonal content artificially removed from the spectrum, such as might be accomplished by an ANC system, the tone-removed levels are compared with the original levels. The system study, described in detail below, is the subject of this report, which is Volume 1 of two volumes that constitute the final report.

Second, a prototype of an lightweight, high efficiency ANC acoustic transducer was developed using a piezoceramic film to actuate an aluminum plate in resonant conditions. Conceptual design studies were made of incorporating piezoceramic material such as PZT (Lead Zirconium Titanate) into an actuator array element for "anti-sound" generation, as a potentially light-weight, more compact alternative to electromagnetic actuator arrays (speakers). The conceptual design study included an assessment of input power requirements and output power and frequency range performance requirements, an analysis of the PZT ring source structure/sound-field interactions, and a conceptual preliminary design specification.

Small scale laboratory tests of PZT-based prototype noise source elements were made to evaluate their characteristics and assess their performance relative to the requirements. Experimental measurements of the PZT element performance characteristics were compared to theoretical predictions, and design modifications for improved performance are evaluated. The development of the piezoceramic transducer and its evaluation are documented in Volume 2 of this final report.

3.3. Objective and Approach of System Noise Studies

In a prior study carried out under NASA Contract NAS3-25269, Task 4, the noise characteristics of four single-rotation engines applied to a 407 Klb takeoff gross weight two-engine aircraft (representative of the Boeing 767) were studied.[12] Four different engine fan pressure ratios characterized the cycles of these engines, 1.3, 1.45, 1.6, and 1.75. The sideline, takeoff, cutback, and approach flight conditions were studied.

In this study, using results of Contract NAS3-25269 Task 4 as a basis, the benefits of active control of fan tone noise on the total noise (EPNL) of selected high bypass engine cycles were assessed. Aircraft flyover noise levels were compared for the untreated, hardwall engine configurations with no applied ANC, the hardwall engine configuration with ANC applied, and the treated engine configuration with no applied ANC. Applying ANC tone removal to the treated configurations was beyond the scope of this study.

A key objective was to determine how the suppression due to ANC tone removal for the hardwall engine compares to suppression due to treatment. The relative benefits of forward versus aft radiated tone noise control were evaluated, and the economic advantages and disadvantages of active control versus conventional noise reduction methods such as passive duct linings were assessed.

Recommendations were made for further research and development of active control of fan noise, including identifying the potential benefits which, based on the results of this study, offers the most promising opportunities for successful application in high bypass ratio aircraft engines.

4. Potential Effect of Active Noise Control on Aircraft System Noise

4.1. Prior Study Conditions

The scope of this program was designed to build upon results previously obtained in NASA Contract NAS3-25629, Task Order 4, in which aircraft system noise studies were conducted over a wide range of engine fan pressure ratio variation for single-rotation fan designs. This study had as its objective an examination of system noise sensitivity to fan pressure ratio for optimization of future Ultrahigh-Bypass Engine (UBE) cycle designs for low noise.

The foreseeable range of fan pressure ratios for advanced single-rotation UBE engines is from a low value of 1.3 to a high of 1.75. Four fan pressure ratio (FPR) values were chosen for the study; 1.3, 1.45, 1.6, and 1.75. The 1.75 FPR represents current state-of-the-art for high bypass ratio engines, while the 1.3 FPR is representative of proposed ultra-high bypass fan designs, and is the lowest value being currently considered, given limitations on fan diameter and installation penalties.

Below a fan pressure ratio of 1.5, speed incompatibilities between the fan and low pressure turbine dictate the need for a gear drive. For all engine cycles with FPR = 1.45 and higher, a mixed flow exhaust was employed to improve performance and reduce jet noise. The engines were sized to 61,500 lbs takeoff thrust, for a two-engine aircraft of 407,000 lb takeoff gross weight. This represents year 2000+ technology levels

The noise component breakdowns for the engines used in this study were based on the E^3 (Energy Efficient Engine) database.[13,14] The E^3 engine database with the hardwall bellmouth inlet and the hardwall exhaust, although not used in Contract NAS3-25269, is used in this study to provide the hardwall baseline from which the tones can be removed. Table 1 compares engine cycle parameters for the baseline engine (based on E^3) to those for the fan pressure ratio variation engine cycles.

Table 1. Engine Cycle Definition for System Noise Studies

Parameter	Baseline E^3	Study Configurations			
FPR	1.62	1.75	1.60	1.45	1.30
BPR	5.8	5.94	7.75	9.81	15.75
OPR	38.5	55	55	55	55
T_{41max}, °F	2504	2800	2800	2800	2800
Flow	Mixed	Mixed	Mixed	Mixed	Mixed
Fan Drive	Direct	Direct	Direct	Geared	Geared
Fan Inlet H/T Ratio	0.342	0.30	0.30	0.30	0.30
Fan Tip Diam, in	99.5	89	96	106	130

Engine data for the baseline 1.62 FPR cycle was adjusted using GEAE methodology to predict the component noise levels for the other fan pressure ratio cycles, per the methods in

Reference 12. In Figures 1 and 2, the database of the hardwall E^3 engine is compared to treated E^3 engine fan inlet and fan exhaust component noise in terms of forward quadrant peak PNL versus fan tip speed for the inlet in Figure 1 and aft quadrant peak PNL versus fan pressure ratio for the exhaust in Figure 2.

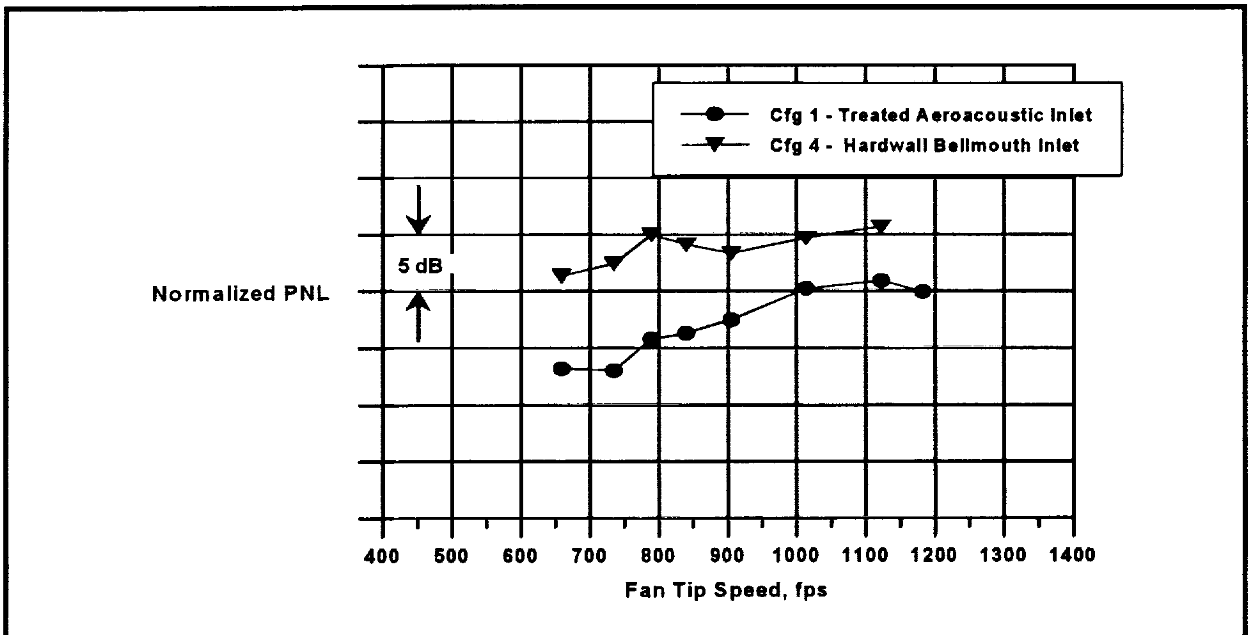

Figure 1. E^3 Normalized Inlet Component Noise, PNL vs. Tip Speed, Treated and Untreated.

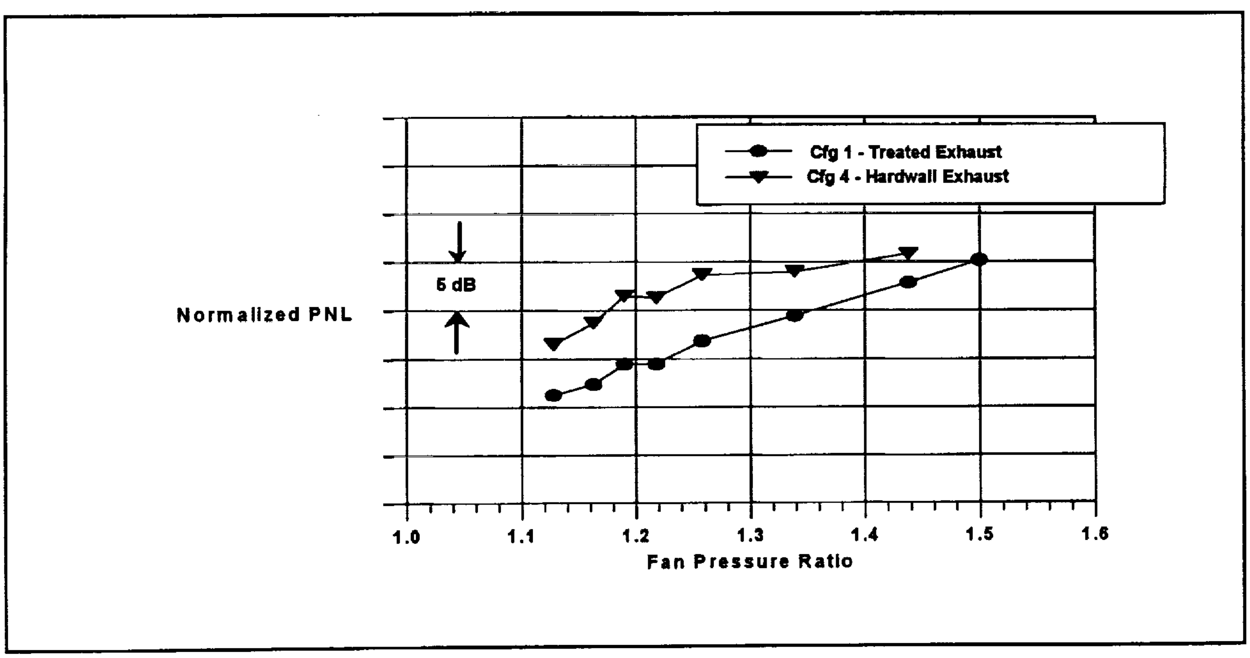

Figure 2. E^3 Normalized Exhaust Component Noise, PNL vs. Fan Pressure Ratio, Treated and Untreated.

4.2. Acoustic Prediction Methodology

Data for the E^3 engine inlet and exhaust radiated levels in hardwall were measured using the Integrated Core/Low Spool (ICLS) engine, as described in Reference 12. The E^3 hardwall engine data were broken into the various engine noise components, including combustor, fan inlet, fan exhaust, and jet noise, using GEAE component noise decomposition methods. Engine cycle parameters, including engine station pressures and temperatures, component mass flows, and engine station flow velocities and Mach numbers, were obtained from cycle analysis. Engine geometric parameters, such as blade and vane numbers, axial spacing, and inlet and exhaust lengths, were given by the flowpath design.

The study engine noise components were obtained by scaling and correcting the component database to the desired study engine cycle conditions using GEAE in-house procedures. The spectra for the fan inlet and exhaust components were then modified by removing the effects of the fan tones. The details of this procedure will be described below. The modified noise components were then synthesized into the study engine noise levels for the new cycle conditions.

The noise components were synthesized into flyover noise prediction levels using the GEAE flyover noise prediction program "FAST". The EPNL levels were calculated accomplished at sideline, takeoff, cutback, and approach flight conditions. The flight path parameters, altitude, Mach number, and engine thrust levels, were provided from the mission analysis for the subject aircraft.

Flyover noise levels for the treated configurations of the engines included in this study were already available from Contract NAS3-25629. Noise level comparisons were made among the hardwall engine levels with no applied ANC, the hardwall levels with applied ANC, and the treated levels with no applied ANC. Applying ANC to the tones of the treated configurations was not within the scope of this study.

4.3. Acoustic Levels Predicted with No Applied ANC

The first step in the procedure is to predict component and overall noise levels of the hardwall configurations of the baseline E^3 engine and the four UBE study engines. The results of the predictions are shown in this section for the baseline engine and the fan pressure ratios of 1.75, 1.60, 1.45, and 1.30. These fan pressure ratios are denoted as Cases S75, S60, S45, and S30, respectively. Predictions are run for sideline, takeoff, cutback, and approach. Approach cases were run both with and without airframe noise.

Table 2. shows the results of the calculations for the baseline engine, where COM denotes combustor, FEX denotes exhaust, FIN denotes inlet, CNJ denotes jet, and AFN denotes airframe noise components. Figure 3. is the corresponding chart of component and overall noise levels at each flight condition. These figures indicate high exhaust noise, but it should be

remembered that there is no exhaust treatment suppression in these cases. Applying the exhaust treatment suppression would reduce exhaust noise to more characteristic levels.

Tables 3. through 6. and corresponding Figures 4. through 7. show the hardwall levels for Cases S75, S60, S45, and S30, respectively. Again, note the relatively high contribution of the fan exhaust noise to the overall levels for all cases. The hardwall noise level data will be used as a baseline to evaluate the suppression due to ANC tone removal.

Table 2. Table of component and overall EPNL levels for baseline hardwall configuration engine.

		EPNL, dB				
	NOISE COMPONENT	SIDELINE 2828 RPM	TAKEOFF 2846 RPM	CUTBACK 2569 RPM	APPROACH 1767 RPM	APPROACH With A/F
FAST PREDICTION	COM	84.2	83.6	82.1	82.0	82.0
	FEX	92.3	91.6	90.6	95.9	95.9
	FIN	89.3	88.0	89.5	98.7	98.7
	CNJ	92.7	91.9	88.1	83.5	83.5
	AFN	—	—	—	—	94.0
	SUM	98.8	98.4	97.1	101.9	103.1

FAST CALIBRATION	1.6	1.6	1.6	1.8	1.8
(PREDICTION-CALIBRATION)	97.2	96.8	95.5	100.1	101.3
FAR-36 RULE	100.1	96.8	96.8	103.6	103.6
MARGIN (RULE-ESTIMATE)	2.9	0.0	1.3	3.5	2.3

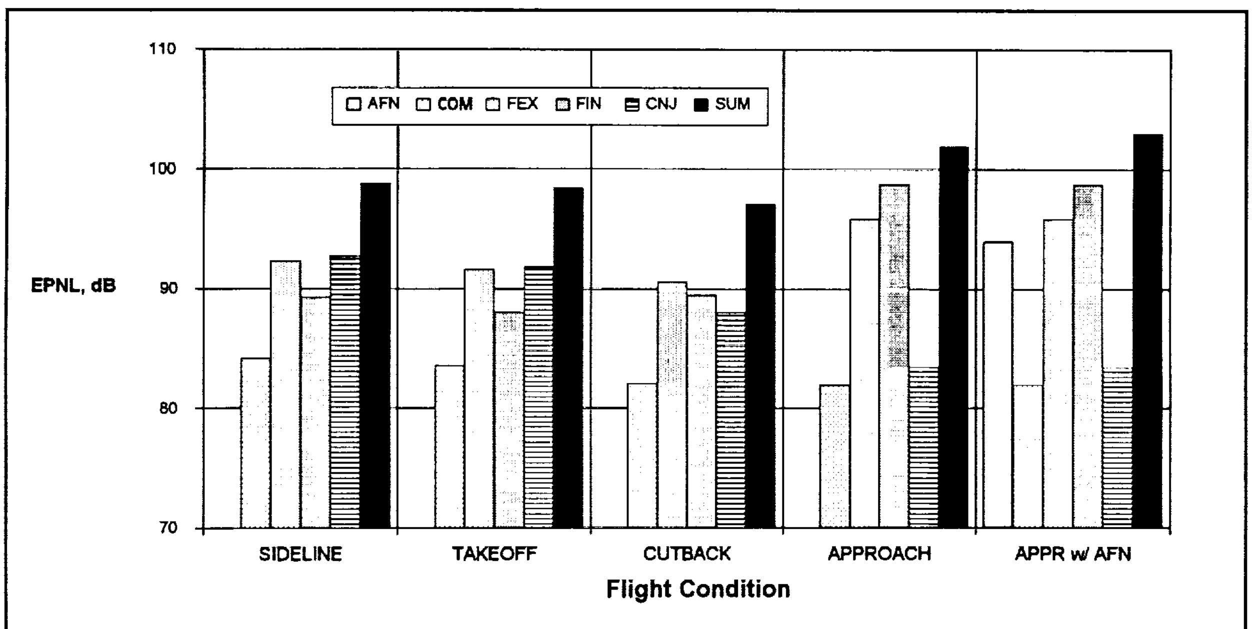

Figure 3. Component and overall EPNL levels for baseline hardwall configuration engine.

Table 3. Table of component and overall EPNL levels for S75 hardwall engine configuration.

S75	NOISE COMPONENT	EPNL, dB SIDELINE 2828 RPM	TAKEOFF 2846 RPM	CUTBACK 2569 RPM	APPROACH 1767 RPM	APPROACH With A/F
FAST PREDICTION	COM	84.6	83.6	81.1	81.0	81.0
	FEX	97.0	95.7	93.0	98.7	98.7
	FIN	89.2	87.3	88.3	99.6	99.6
	CNJ	96.5	95.7	90.5	85.3	85.3
	AFN	—	—	—	—	94.0
	SUM	102.2	101.3	97.9	103.5	104.3
FAST CALIBRATION		1.6	1.6	1.6	1.8	1.8
(PREDICTION-CALIBRATION)		100.6	99.7	96.3	101.7	102.5
FAR-36 RULE		100.1	96.8	96.8	103.6	103.6
MARGIN (RULE-ESTIMATE)		-0.5	-2.9	0.5	1.9	1.1

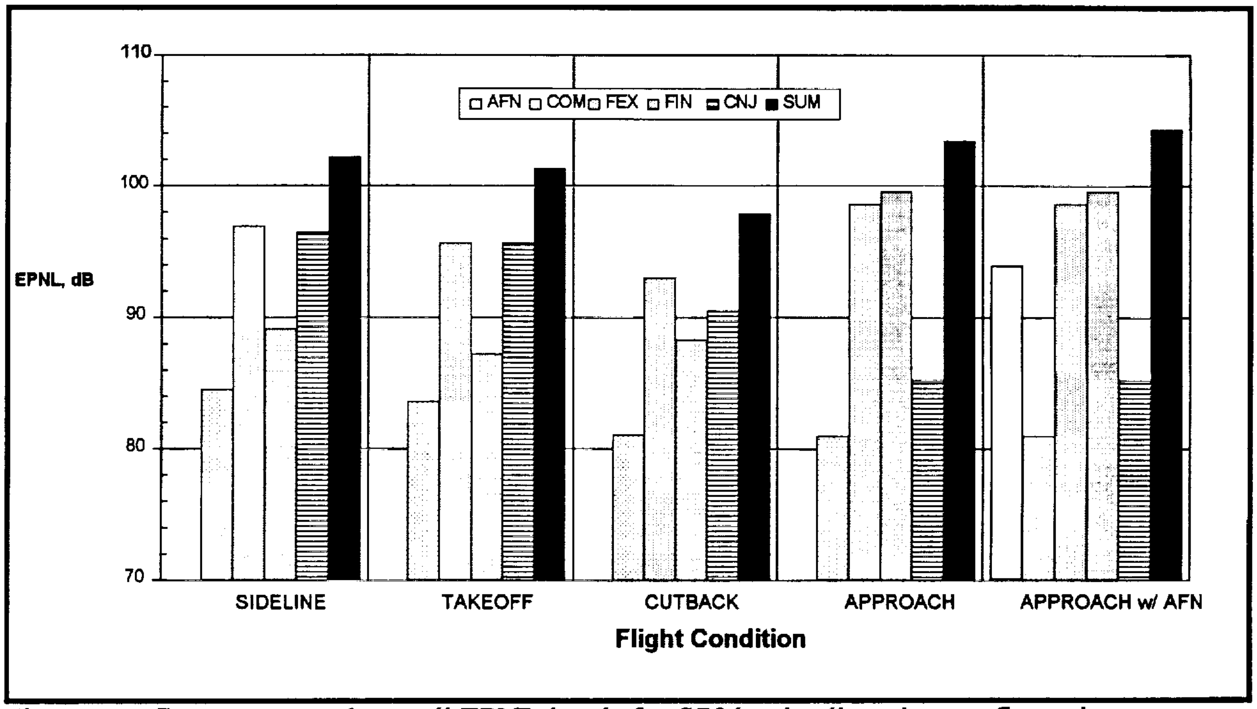

Figure 4. Component and overall EPNL levels for S75 hardwall engine configuration.

Table 4. Table of component and overall EPNL levels for S60 hardwall engine configuration.

S60	NOISE COMPONENT	EPNL, dB SIDELINE 2828 RPM	TAKEOFF 2846 RPM	CUTBACK 2569 RPM	APPROACH 1767 RPM	APPROACH With AFN
FAST PREDICTION	COM	83.9	82.9	80.5	80.5	80.5
	FEX	95.7	94.8	92.8	96.1	96.1
	FIN	90.2	88.5	88.9	101.7	101.7
	CNJ	92.9	91.9	87.3	83.4	83.4
	AFN	—	—	—	—	94.0
	SUM	100.3	99.4	96.9	103.6	104.4

FAST CALIBRATION	1.6	1.6	1.6	1.8	1.8
(PREDICTION-CALIBRATION)	98.7	97.8	95.3	101.8	102.6
FAR-36 RULE	100.1	96.8	96.8	103.6	103.6
MARGIN (RULE-ESTIMATE)	1.4	-1.0	1.5	1.8	1.0

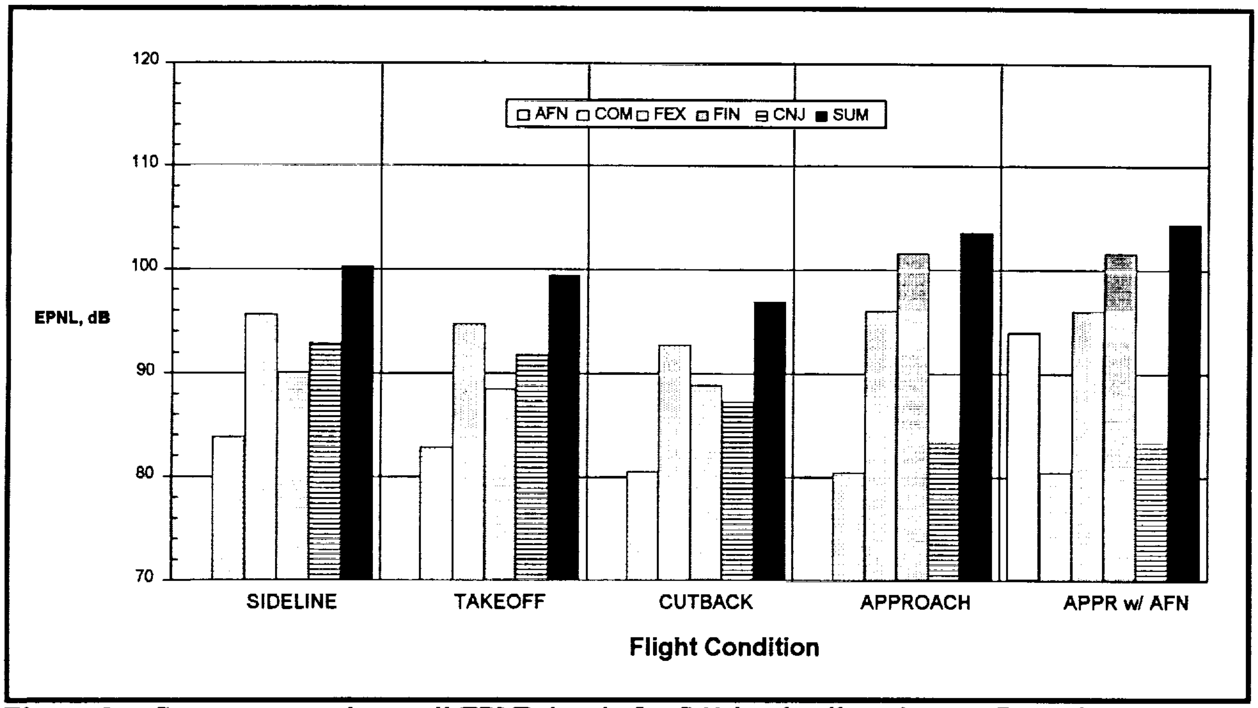

Figure 5. Component and overall EPNL levels for S60 hardwall engine configuration.

Table 5. Table of component and overall EPNL levels for S45 hardwall engine configuration.

S45	NOISE COMPONENT	EPNL, dB SIDELINE 2828 RPM	TAKEOFF 2846 RPM	CUTBACK 2569 RPM	APPROACH 1767 RPM	APPROACH With A/F
FAST PREDICTION	COM	83.7	82.8	80.1	80.3	80.3
	FEX	95.3	93.8	91.8	97.5	97.5
	FIN	89.2	87.4	85.5	98.2	98.2
	CNJ	89.1	88.2	84.1	83.6	84.2
	AFN	—	—	—	—	94.0
	SUM	99.0	97.5	94.9	101.9	103.2

	SIDELINE	TAKEOFF	CUTBACK	APPROACH	APPROACH With A/F
FAST CALIBRATION	1.6	1.6	1.6	1.8	1.8
(PREDICTION-CALIBRATION)	97.4	95.9	93.3	100.1	101.4
FAR-36 RULE	100.1	96.8	96.8	103.6	103.6
MARGIN (RULE-ESTIMATE)	2.7	0.9	3.5	3.5	2.2

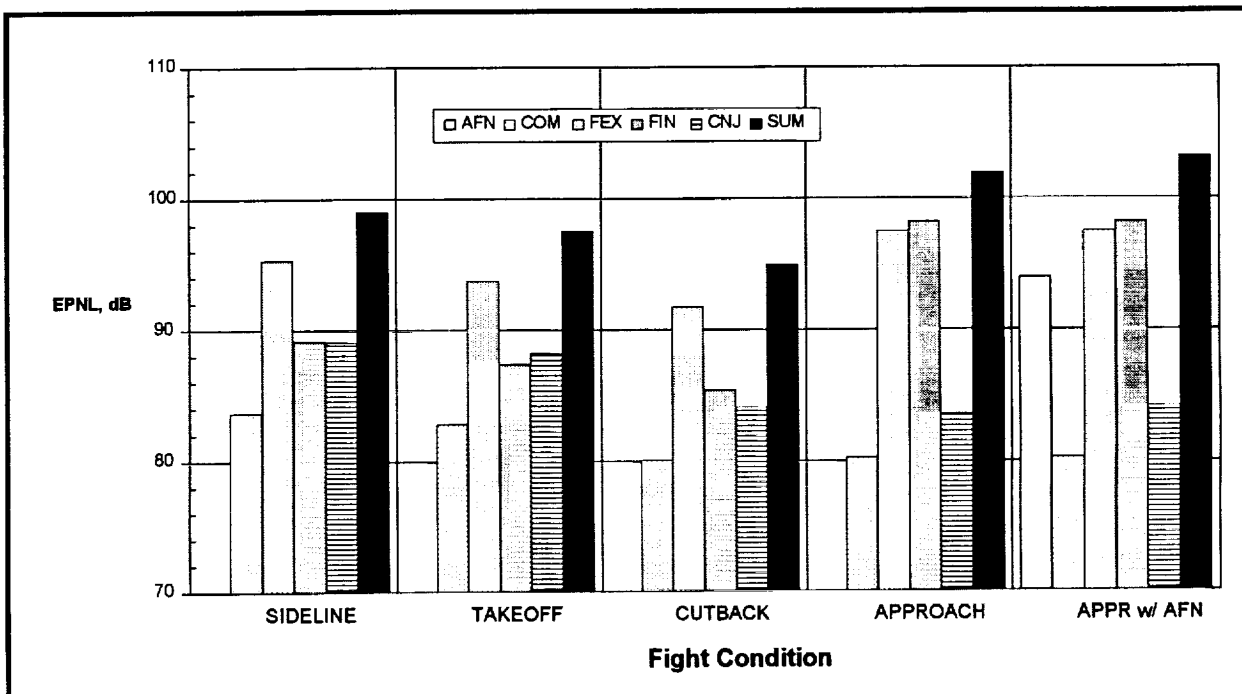

Figure 6. Component and overall EPNL levels for S45 hardwall engine configuration.

Table 6. Table of component and overall EPNL levels for S45 hardwall engine configuration.

S30	NOISE COMPONENT	SIDELINE 2828 RPM	TAKEOFF 2846 RPM	CUTBACK 2569 RPM	APPROACH 1767 RPM	APPROACH With A/F
		EPNL, dB				
FAST PREDICTION	COM	82.3	81.4	79.3	79.6	79.6
	FEX	94.6	93.5	92.4	96.5	96.5
	FIN	91.0	88.6	88.3	95.6	95.6
	SFJ	85.3	84.3	81.5	83.3	83.3
	AFN	—	—	—	—	94.0
	SUM	98.3	97.0	95.6	100.4	101.6
FAST CALIBRATION		1.6	1.6	1.6	1.8	1.8
(PREDICTION-CALIBRATION)		96.7	95.4	94.0	98.6	99.8
FAR-36 RULE		100.1	96.8	96.8	103.6	103.6
MARGIN (RULE-ESTIMATE)		3.4	1.4	2.8	5.1	3.8

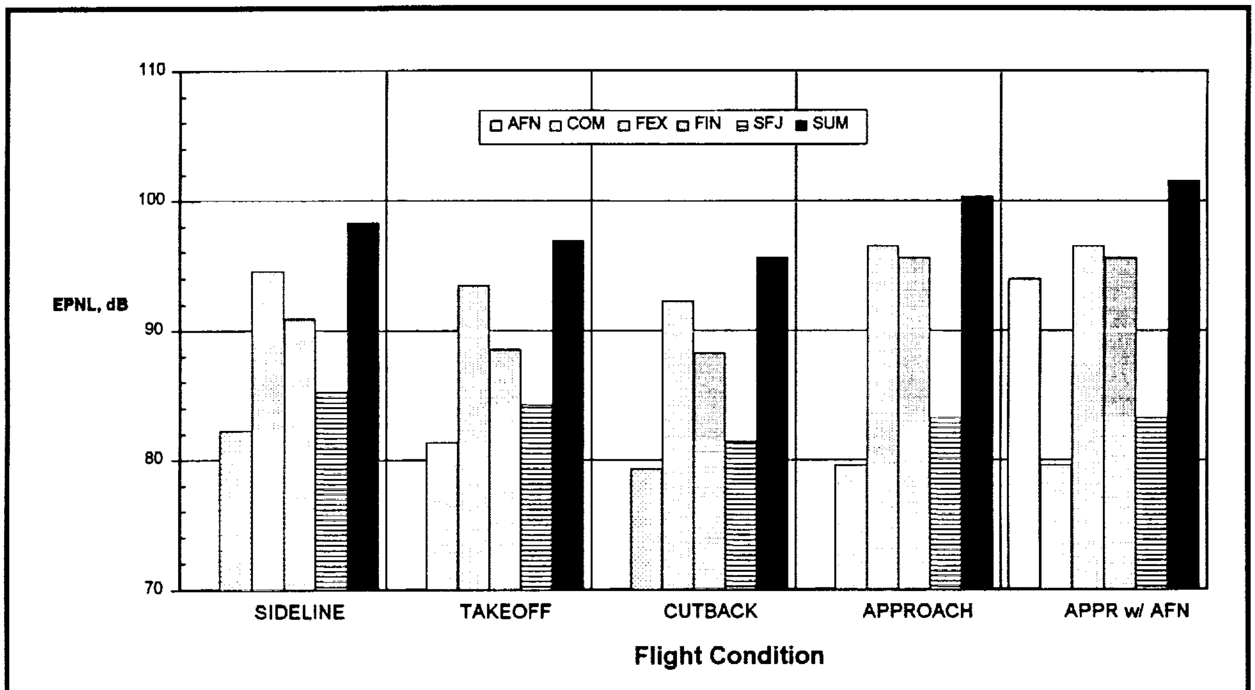

Figure 7. Component and overall EPNL levels for S30 hardwall engine configuration.

4.4. Determination of Tone Protrusions Above Broadband Levels

Tone protrusions are determined in FAST by identifying those third octave bands in which the blade passing frequency and its higher harmonics are located and comparing the levels in these tonal third octave bands to the surrounding broadband-controlled third octaves. The FAST printout was modified to provide tone and broadband third octave data for both inlet and exhaust radiated fan noise. The tone protrusions (tone level minus surrounding broadband level) were then computed over the angular range of the data for the third octave bands that correspond to blade passing frequency (BPF), the second harmonic of blade passing frequency (2BPF), and the third harmonic of blade passing frequency (3BPF).

Plots of directivity patterns for forward and aft radiated fan noise for each of the engines at each operating condition were prepared. For each engine and operating condition, the maximum tone protrusion above the broadband level was for both the forward and aft radiated components. The maximum tone protrusions for each engine and operating condition for fan inlet and fan exhaust are presented in Table 7.

Table 7. Maximum protrusion of tones above broadband level, 1/3 octave band SPL, dB

		Fan Inlet				*Fan Exhaust*			
Engine	*Tone*	*S/L*	*T/O*	*C/B*	*APP*	*S/L*	*T/O*	*C/B*	*APP*
	BPF	13.0	13.0	13.2	7.3	8.6	8.6	6.9	6.4
S75	*2BPF*	5.6	5.6	6.7	4.5	4.3	4.3	6.0	2.2
	3BPF	2.8	2.8	4.4	2.9	2.3	2.3	6.2	0.0
	BPF	13.9	13.9	13.2	11.5	7.9	7.9	7.0	12.5
S60	*2BPF*	7.4	7.4	6.7	3.2	3.8	3.8	2.7	2.2
	3BPF	5.4	5.4	3.0	0.0	6.8	6.8	2.4	0.0
	BPF	13.0	13.0	14.3	4.8	7.9	7.5	11.8	5.3
S45	*2BPF*	4.5	4.8	2.1	0.0	5.2	4.5	2.4	0.0
	3BPF	7.9	7.2	4.8	13.8	7.5	8.1	1.0	0.0
	BPF	12.3	12.5	7.7	3.6	9.8	9.8	11.2	2.1
S30	*2BPF*	5.2	5.0	0.0	3.1	2.5	2.5	2.4	0.0
	3BPF	7.3	7.5	3.3	10.9	3.3	3.6	0.0	0.0

The results of these tone protrusion calculations can be used to identify those cases that are most amenable to active noise control suppression. Several conclusions can be drawn from an examination of the data:

- The forward radiated tones protrude further from the broadband noise levels than do the aft radiated tones.

- The magnitude of the tone protrusions for BPF, 2BPF, and 3BPF are roughly similar for the S75 and the S60 cases, and for the S45 and the S30 cases.

- The tone protrusions at 2BPF and 3BPF are generally much smaller in magnitude than those at BPF.

- The tone protrusions at approach speed are generally much lower in both the inlet and exhaust than at the higher sideline, takeoff, and cutback speeds. The only exceptions to this are the S60 engine BPF exhaust, the S45 engine 3BPF inlet, and the S30 engine 3BPF inlet.

Based on these results, the S75 and the S45 engines were chosen for further study. It is assumed that the results for the S60 engine would be similar to the S75 and the results for the S30 engine would be similar to the S45.

4.5. Effects of ANC Tone Removal

4.5.1. Full Reduction of Tones

In addition to limiting the study of effects of tone removal to the S75 (1.75 FPR) and the S45 (1.45 FPR) cases, it was found that the tone protrusions of the sideline and takeoff rpms of both engines were nearly identical, so that the examination of the takeoff case was eliminated. This reduced the study matrix to six cases, i.e., two engines at three flight conditions.

The values of the maximum tone protrusion were considered as an ANC reduction and applied at all angles, by subtracting them from the SPL in the third octave band that contained the harmonic. For each case, ten independent runs of the FAST program were made, in the following combinations:

Inlet (FIN) only:	1) BPF only
	2) 2BPF only
	3) 3BPF only
	4) BPF, 2BPF, and 3BPF
Exhaust (FEX) only:	1) BPF only
	2) 2BPF only
	3) 3BPF only
	4) BPF, 2BPF, and 3BPF
FIN and FEX:	1) BPF only
	2) BPF, 2BPF, and 3BPF

The results of comparing the original hardwall engine levels presented previously with the levels calculated with the tones removed in the above combinations are summarized in Table 8 for the S75 engine, and in Table 9 for the S45 engine, in terms of EPNL benefit due to removing the tones. For comparison, the benefit of passive acoustic treatment for the hardwall engines, where the treatment works on both the tones and the broadband noise, is presented at the bottom of the tables.

The ANC benefit results are presented graphically in Figures 8 through 13, in terms of ΔEPNdB. The overall EPNL levels with and without the removal of the tones are compared in Tables 10 through 12 and Tables 13 through 15 for the S75 and S45 engines, respectively, and graphically in Figures 14 through 16 for the S75 engine and in Figures 17 through 19 for the S45 engine.

Table 8. Effect of applying active noise control to BPF, 2BPF, and 3BPF on engine S75, compared to effect of passive treatment.

S75	Sideline			Cutback			Approach		
ANC Applied	***EPNL Benefit***			***EPNL Benefit***			***EPNL Benefit***		
Fan Inlet Only	FIN	FEX	SUM	FIN	FEX	SUM	FIN	FEX	SUM
1BPF	5.2		0.3	5.9		0.6	1.5		0.6
2BPF	0		0	0		0	0.3		0.1
3BPF	0		0	0		0	0.3		0.1
All BPFs	5.6		0.3	5.9		0.6	2.0		0.8
Fan Exhaust Only	FIN	FEX	SUM	FIN	FEX	SUM	FIN	FEX	SUM
1BPF		2.9	1.6		2.5	1.4		0.6	0.3
2BPF		0.1	0.1		0.1	0		0.1	0
3BPF		0	0		0	0.1		0	0
All BPFs		3.4	1.9		2.6	1.4		0.9	0.3
Fan Inlet & Exhaust	FIN	FEX	SUM	FIN	FEX	SUM	FIN	FEX	SUM
1BPF	5.1	2.9	2.1	5.9	2.5	2.6	1.5	0.6	0.8
All BPFs	5.5	3.4	2.5	6.1	2.6	2.7	2.0	0.9	1.0
	FIN	FEX	SUM	FIN	FEX	SUM	FIN	FEX	SUM
Passive Treatment	5.8	2.3	1.8	6.1	2.0	2.1	4.3	6.4	3.9

Table 9. Effect of applying active noise control to BPF, 2BPF, and 3BPF on engine S45, compared to effect of passive treatment.

S45	Sideline			Cutback			Approach		
ANC Applied	***EPNL Benefit***			***EPNL Benefit***			***EPNL Benefit***		
Fan Inlet Only	FIN	FEX	SUM	FIN	FEX	SUM	FIN	FEX	SUM
1BPF	2.8		0.5	0.8		0.1	0.1		0.0
2BPF	0		0	0		0	0.0		0.0
3BPF	0		0	0		0	3.5		1.5
All BPFs	3.2		0.6	1.4		0.2	3.4		1.6
Fan Exhaust Only	FIN	FEX	SUM	FIN	FEX	SUM	FIN	FEX	SUM
1BPF		0.5	0.4		0.6	0.4		0.3	0.1
2BPF		0.2	0.1		0.3	0		0.0	0
3BPF		1	1		0	0.1		0	0
All BPFs		3.4	2.1		1.3	0.7		0.5	0.1
Fan Inlet & Exhaust	FIN	FEX	SUM	FIN	FEX	SUM	FIN	FEX	SUM
1BPF	2.7	0.5	0.8	0.8	0.6	0.5	0.1	0.1	0.1
All BPFs	3.2	3.4	3.1	1.7	1.3	1.0	3.4	0.5	1.7
	FIN	FEX	SUM	FIN	FEX	SUM	FIN	FEX	SUM
Passive Treatment	5.2	4.1	3.2	6.0	6.2	4.7	4.3	4.7	3.4

Table 10. ANC tone-removed EPNL for S75 at sideline.

ANC Tone Suppression Applied To:						SIDELINE EPNL		
Fan Inlet			Fan Exhaust			FIN	FEX	SUM
						89.2	97.0	102.2
BPF						84.0	97.0	101.9
	2BPF					89.2	97.0	102.2
		3BPF				89.1	97.0	102.2
BPF	2BPF	3BPF				83.6	97.0	101.9
			BPF			89.3	94.1	100.6
				2BPF		89.2	96.8	102.1
					3BPF	89.2	97.0	102.2
			BPF	2BPF	3BPF	89.3	93.6	100.3
BPF			BPF			84.0	94.1	100.1
BPF	2BPF	3BPF	BPF	2BPF	3BPF	83.6	93.6	99.7

Table 11. ANC tone-removed EPNL for S75 at cutback.

ANC Tone Suppression Applied To:						CUTBACK EPNL		
Fan Inlet			Fan Exhaust			FIN	FEX	SUM
						88.3	93.0	97.9
BPF						82.4	93.1	97.3
	2BPF					88.3	93.0	97.9
		3BPF				88.3	93.0	97.9
BPF	2BPF	3BPF				82.4	93.1	97.3
			BPF			88.2	90.5	96.6
				2BPF		88.3	92.9	97.9
					3BPF	88.3	93.0	97.8
			BPF	2BPF	3BPF	88.2	90.4	96.5
BPF			BPF			82.4	90.5	95.4
BPF	2BPF	3BPF	BPF	2BPF	3BPF	82.2	90.4	95.2

Table 12. ANC tone-removed EPNL for S75 at approach.

ANC Tone Suppression Applied To:						APPROACH EPNL		
Fan Inlet			Fan Exhaust			FIN	FEX	SUM
						99.6	98.7	104.3
BPF						98.1	98.7	103.7
	2BPF					99.3	98.7	104.2
		3BPF				99.4	98.7	104.2
BPF	2BPF	3BPF				97.6	98.7	103.5
			BPF			99.6	98.1	104.1
				2BPF		99.6	98.6	104.3
					3BPF	99.6	98.7	104.3
			BPF	2BPF	3BPF	99.6	97.7	104.0
BPF			BPF			98.1	98.1	103.5
BPF	2BPF	3BPF	BPF	2BPF	3BPF	97.6	97.7	103.3

Table 13. ANC tone-removed EPNL for S45 at sideline.

ANC Tone Suppression Applied To:						SIDELINE EPNL		
Fan Inlet			Fan Exhaust			FIN	FEX	SUM
						89.2	95.3	99.0
BPF						86.4	95.3	98.5
	2BPF					89.0	95.3	99.0
		3BPF				88.8	95.3	98.8
BPF	2BPF	3BPF				86.0	95.3	98.4
			BPF			89.2	94.8	98.6
				2BPF		89.2	95.1	98.9
					3BPF	89.2	94.0	98.1
			BPF	2BPF	3BPF	89.2	91.9	96.9
BPF			BPF			86.5	94.8	98.2
BPF	2BPF	3BPF	BPF	2BPF	3BPF	86.0	91.9	95.9

Table 14. ANC tone-removed EPNL for S45 engine at cutback.

ANC Tone Suppression Applied To:						CUTBACK EPNL		
Fan Inlet			Fan Exhaust			FIN	FEX	SUM
						85.5	91.8	94.9
BPF						84.7	91.8	94.8
	2BPF					85.4	91.8	94.9
		3BPF				85.0	91.8	94.8
BPF	2BPF	3BPF				84.0	91.8	94.7
			BPF			85.5	91.2	94.5
				2BPF		85.5	91.5	94.8
					3BPF	85.5	91.5	94.8
			BPF	2BPF	3BPF	85.5	90.5	94.2
BPF			BPF			84.7	91.2	94.4
BPF	2BPF	3BPF	BPF	2BPF	3BPF	83.8	90.5	94.0

Table 15. ANC tone-removed EPNL for S45 engine at approach.

ANC Tone Suppression Applied To:						APPROACH EPNL		
Fan Inlet			Fan Exhaust			FIN	FEX	SUM
						98.2	97.5	103.2
BPF						98.1	97.5	103.1
	2BPF					98.2	97.5	103.2
		3BPF				94.7	97.5	101.6
BPF	2BPF	3BPF				94.8	97.5	101.6
			BPF			98.2	97.2	103.1
				2BPF		98.2	97.5	103.2
					3BPF	98.2	97.2	103.1
			BPF	2BPF	3BPF	98.2	97.0	103.0
BPF			BPF			98.1	97.4	103.1
BPF	2BPF	3BPF	BPF	2BPF	3BPF	94.8	97.0	101.5

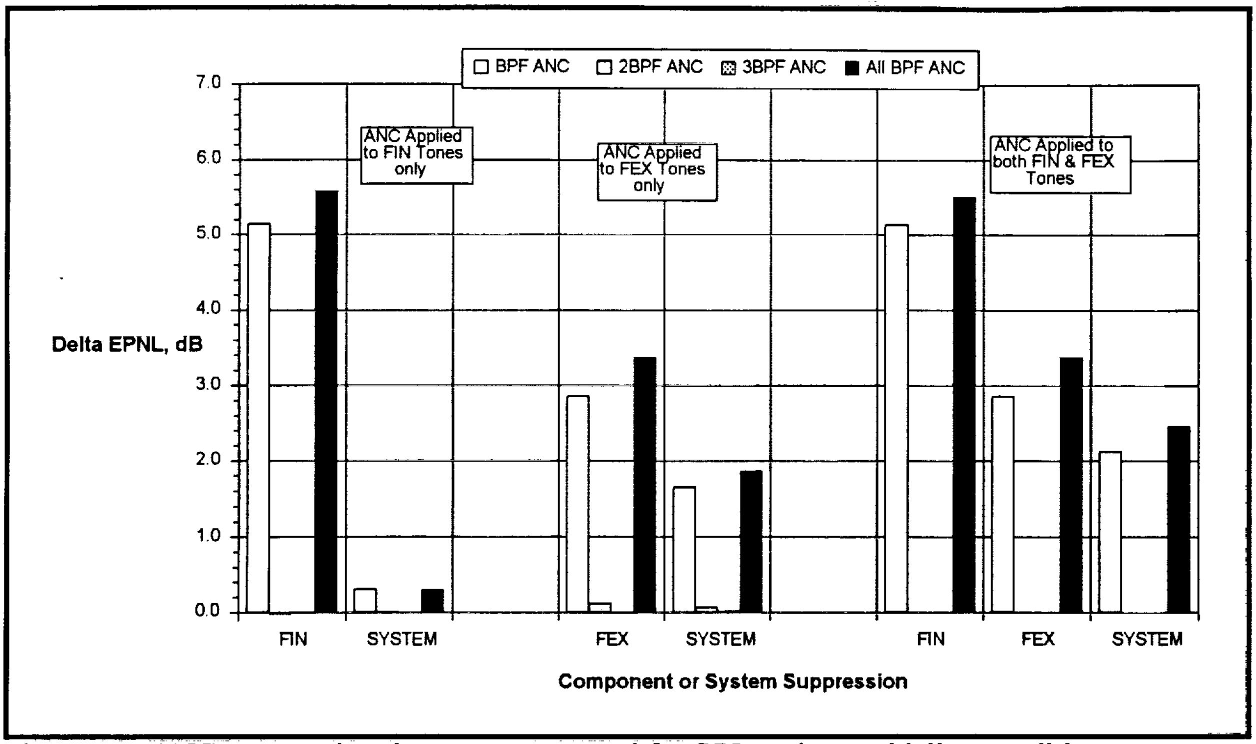

Figure 8. ANC suppression due to tone removal for S75 engine at sideline condition.

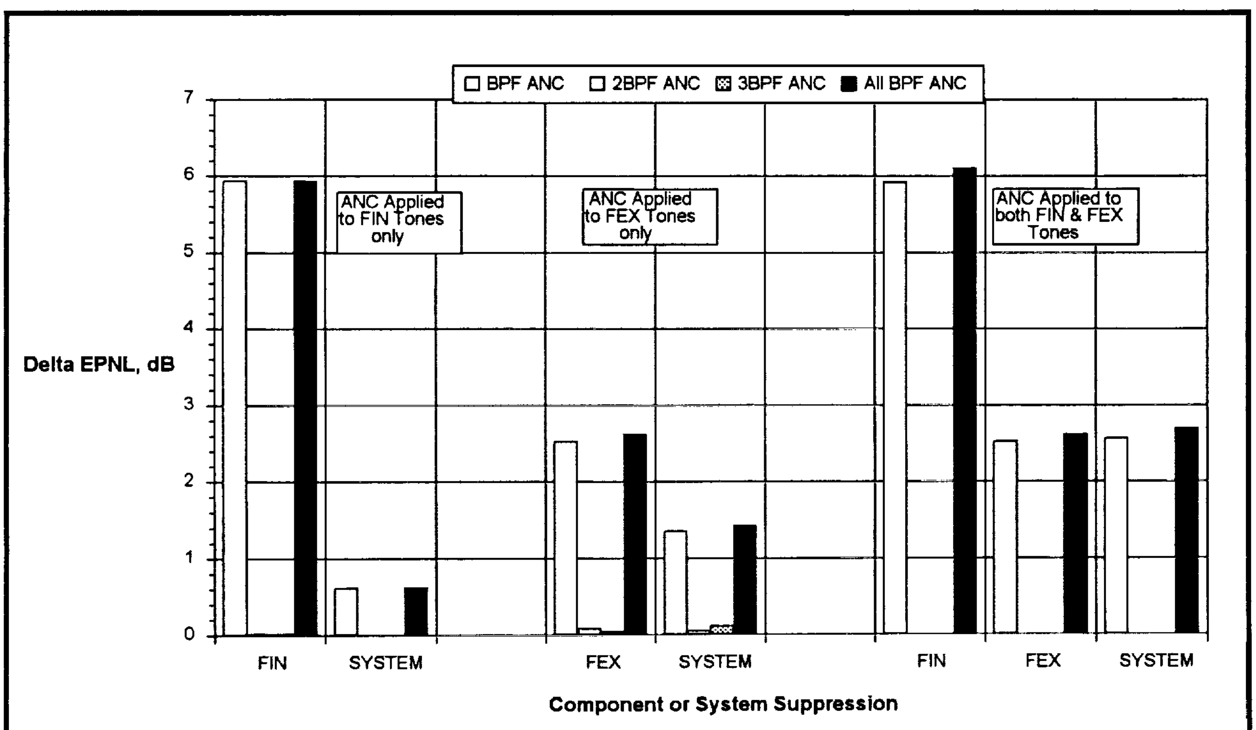

Figure 9. ANC suppression due to tone removal for S75 engine at cutback condition.

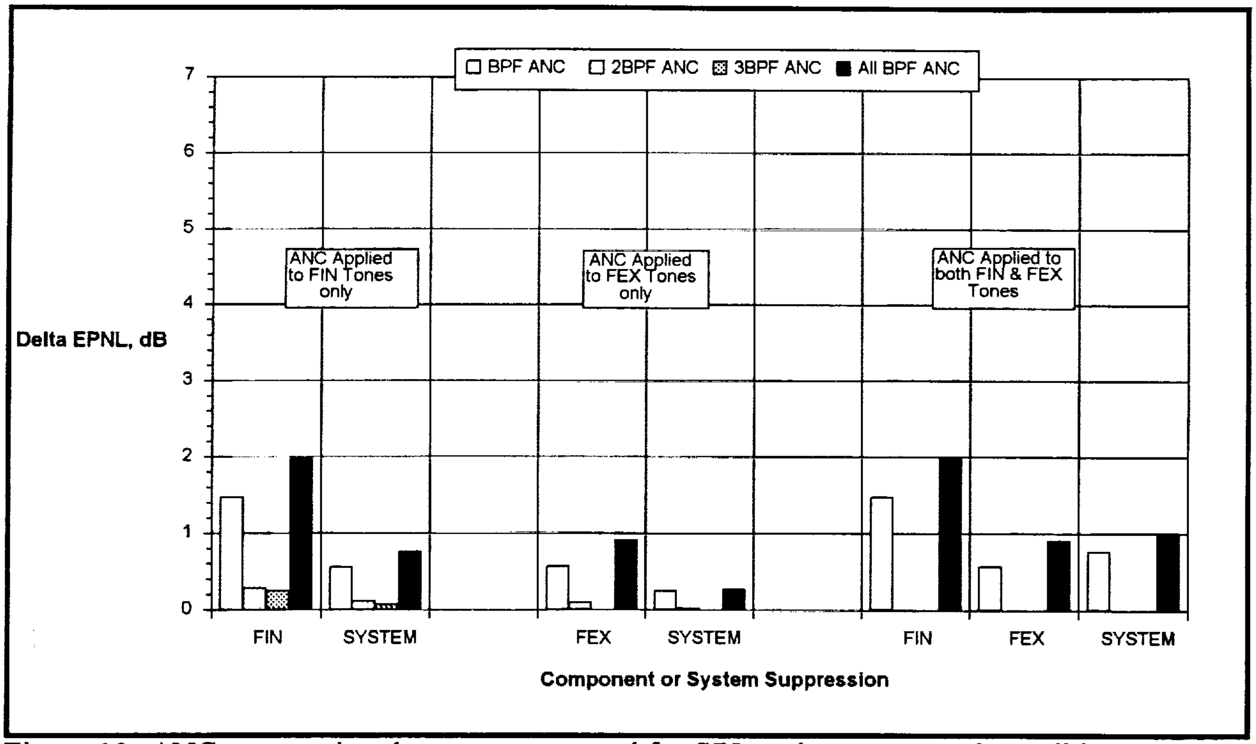

Figure 10. ANC suppression due to tone removal for S75 engine at approach condition.

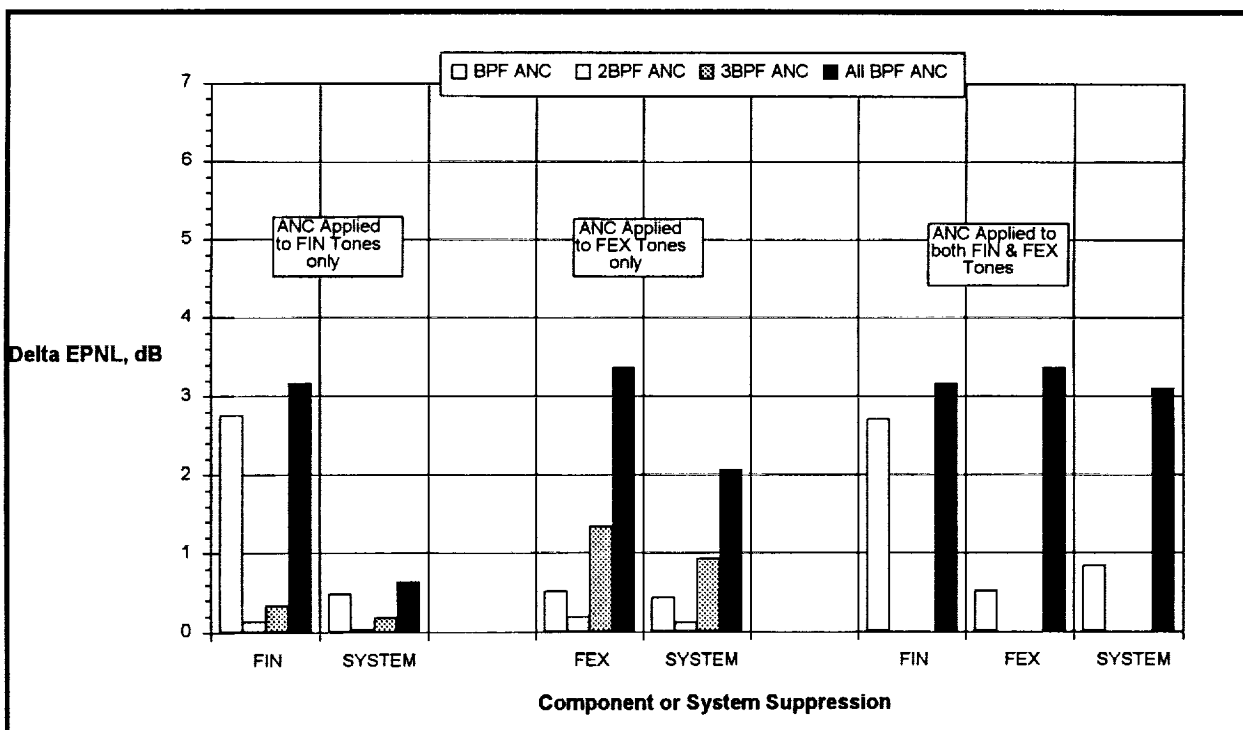

Figure 11. ANC suppression due to tone removal for S45 engine at sideline condition.

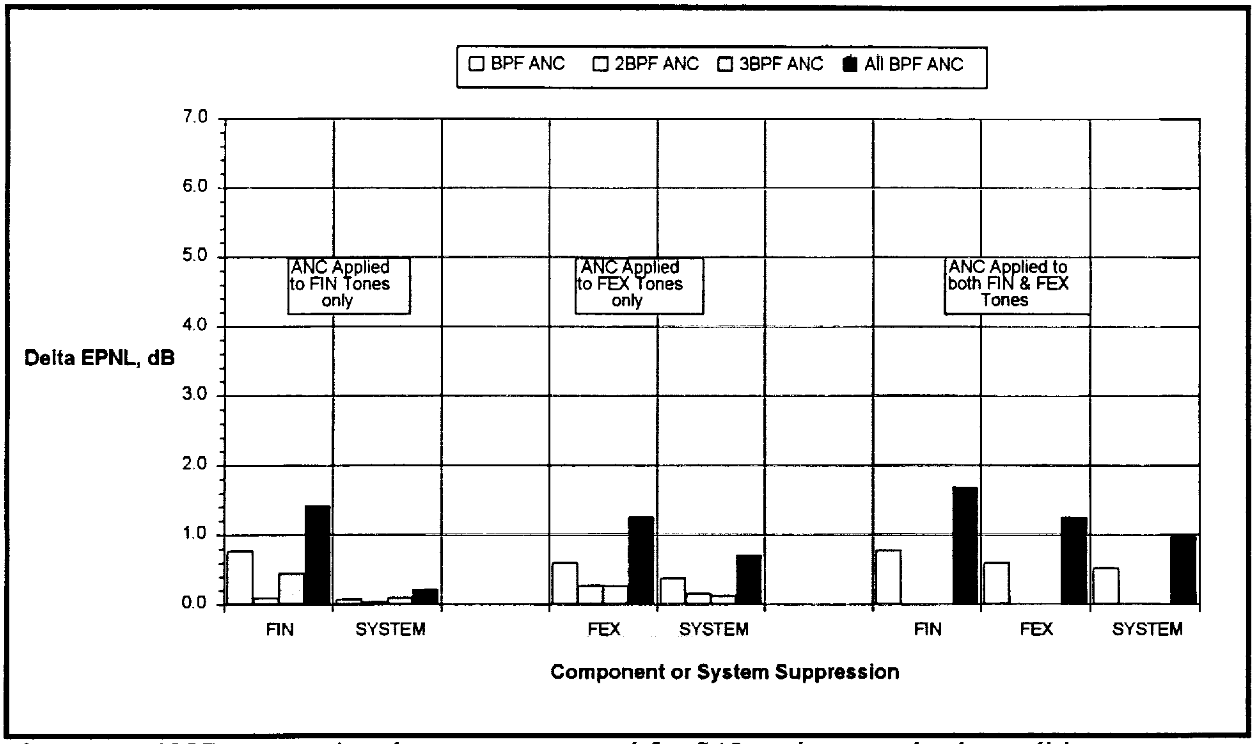

Figure 12. ANC suppression due to tone removal for S45 engine at cutback condition.

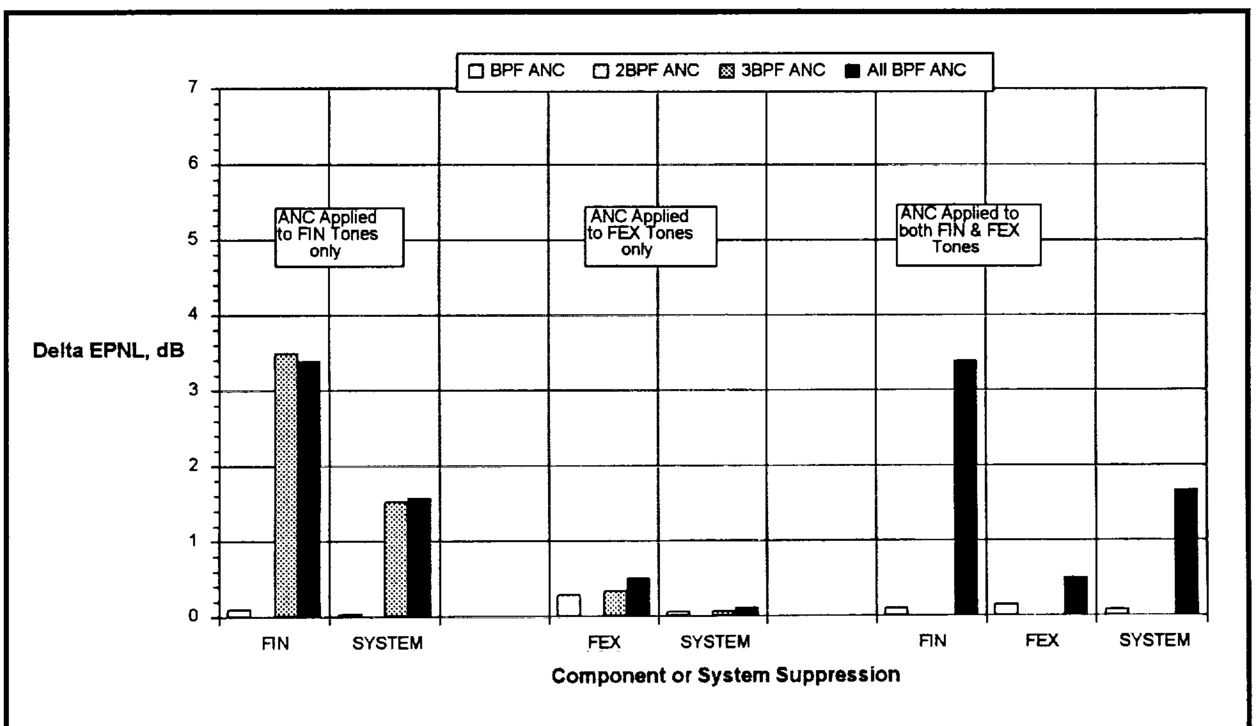

Figure 13. ANC suppression due to tone removal for S45 engine at approach condition.

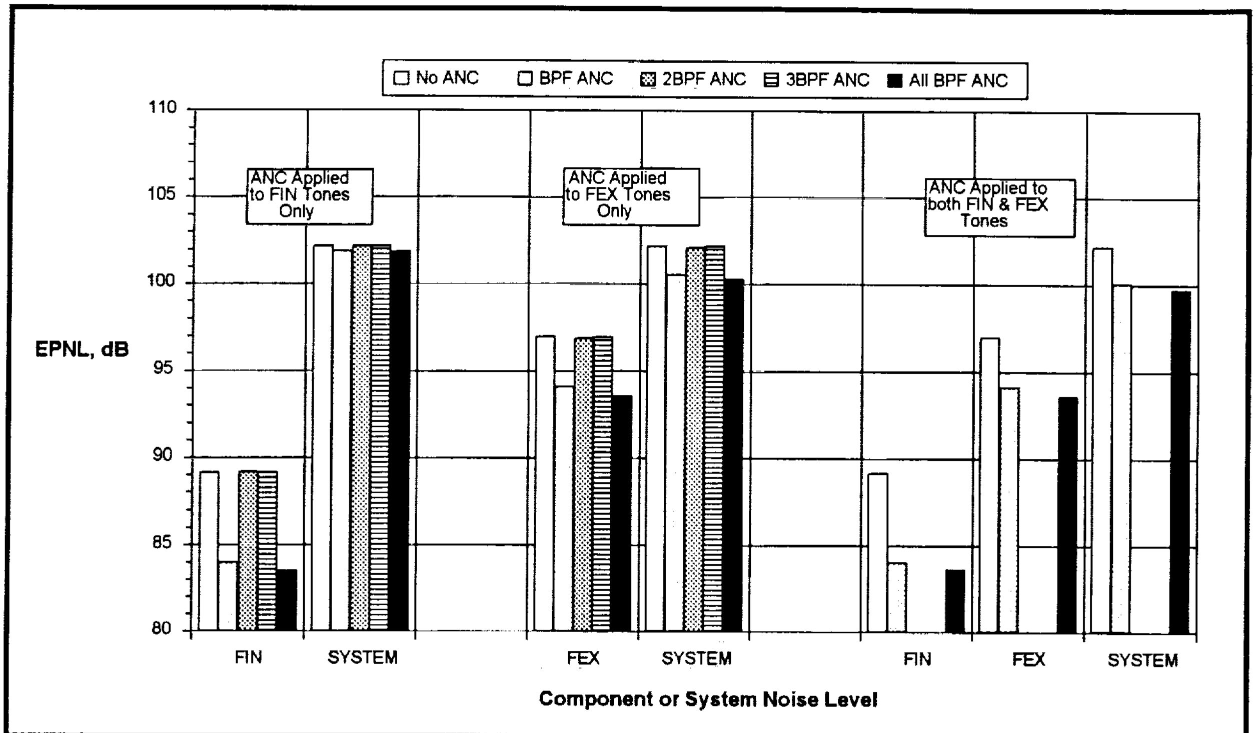

Figure 14. EPNL with and without ANC for components and system, S75 engine at sideline.

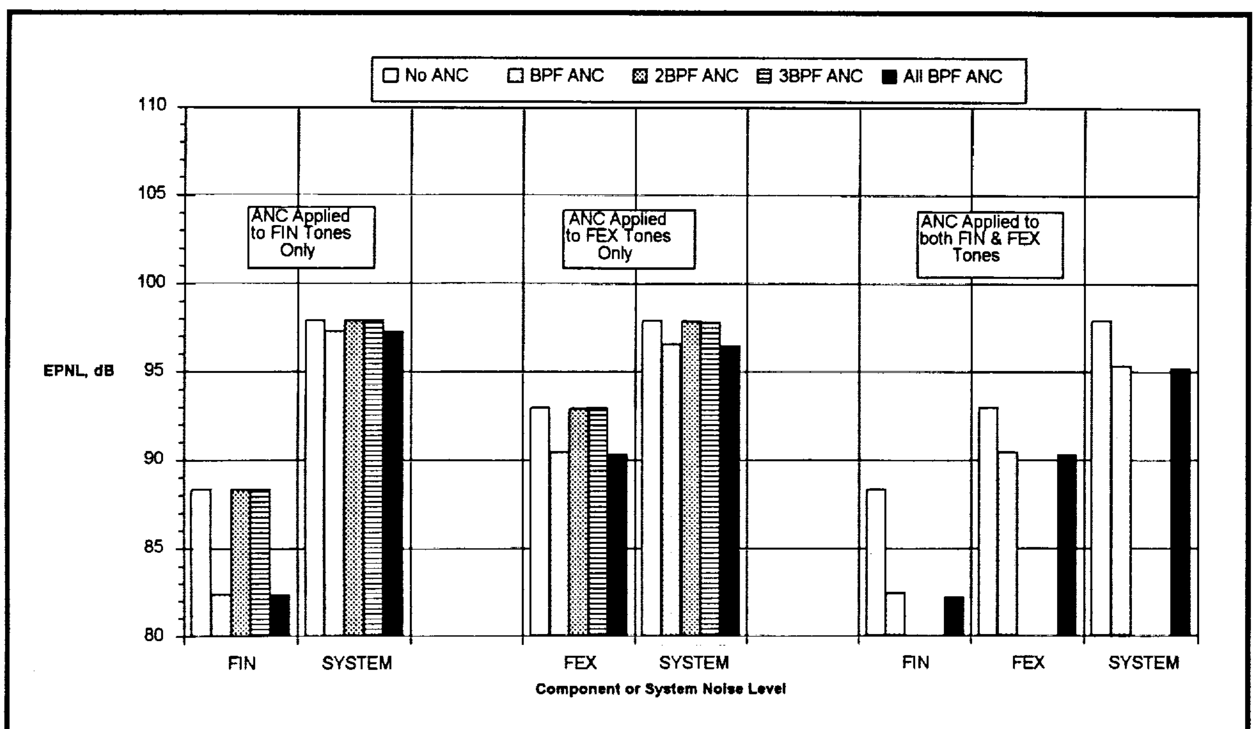

Figure 15. EPNL with and without ANC for components and system, S75 engine at cutback.

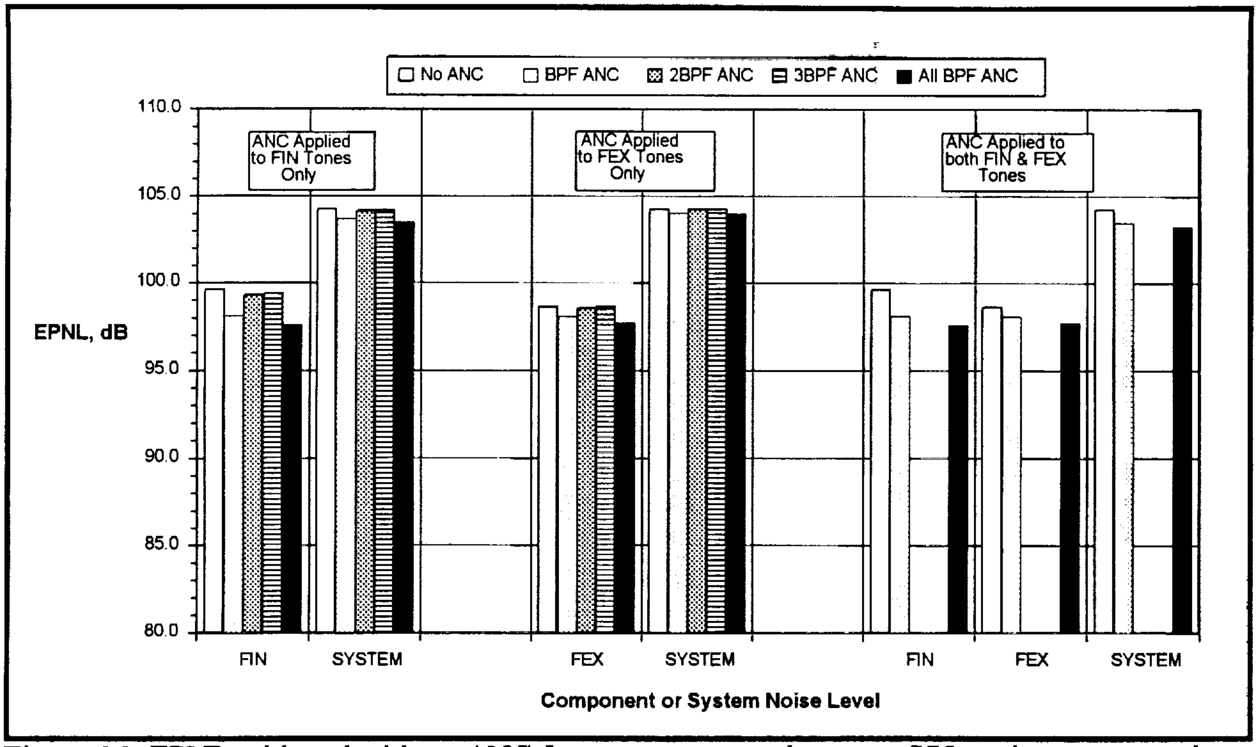

Figure 16. EPNL with and without ANC for components and system, S75 engine at approach.

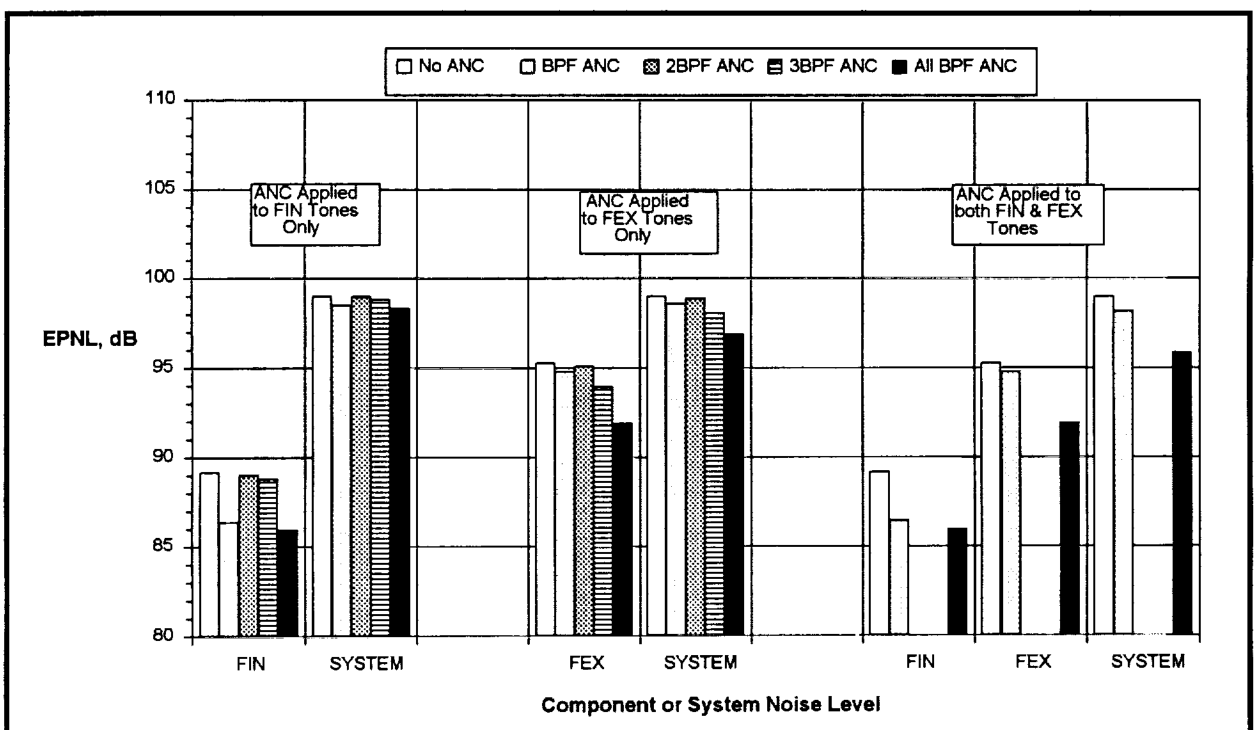

Figure 17. EPNL with and without ANC for components and system, S45 engine at sideline.

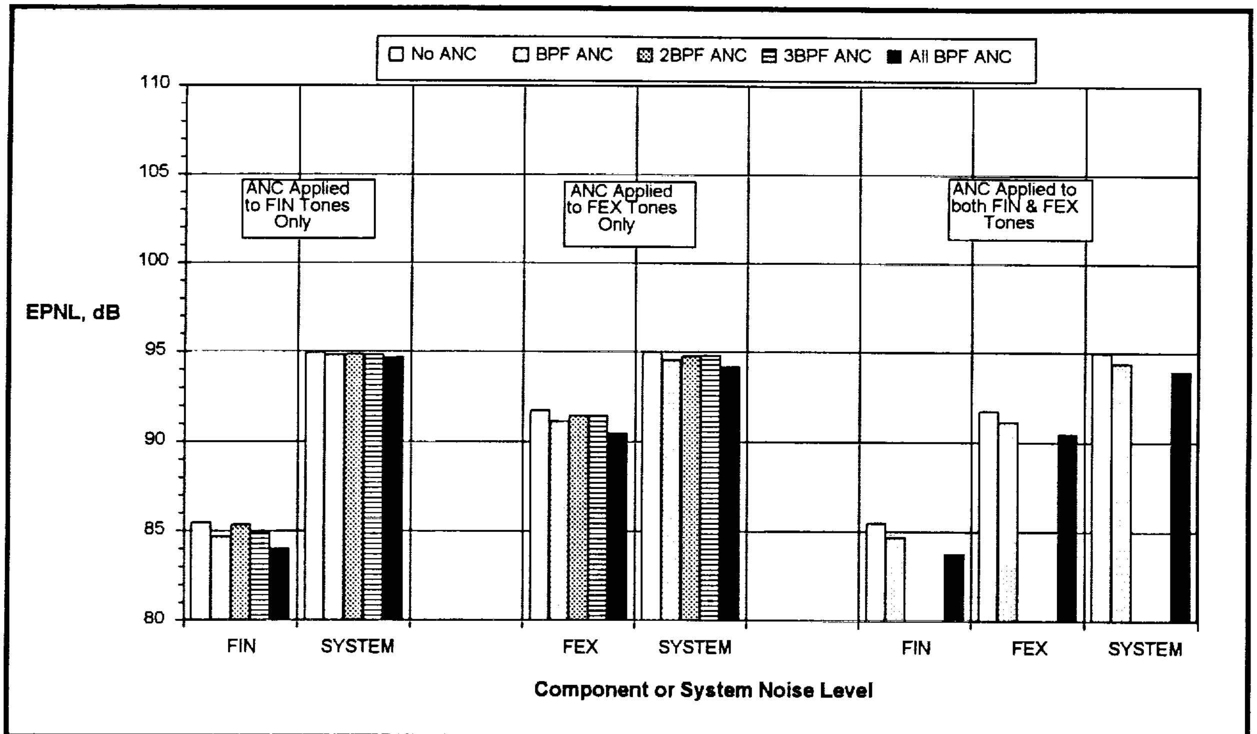

Figure 18. EPNL with and without ANC for components and system, S45 engine at cutback.

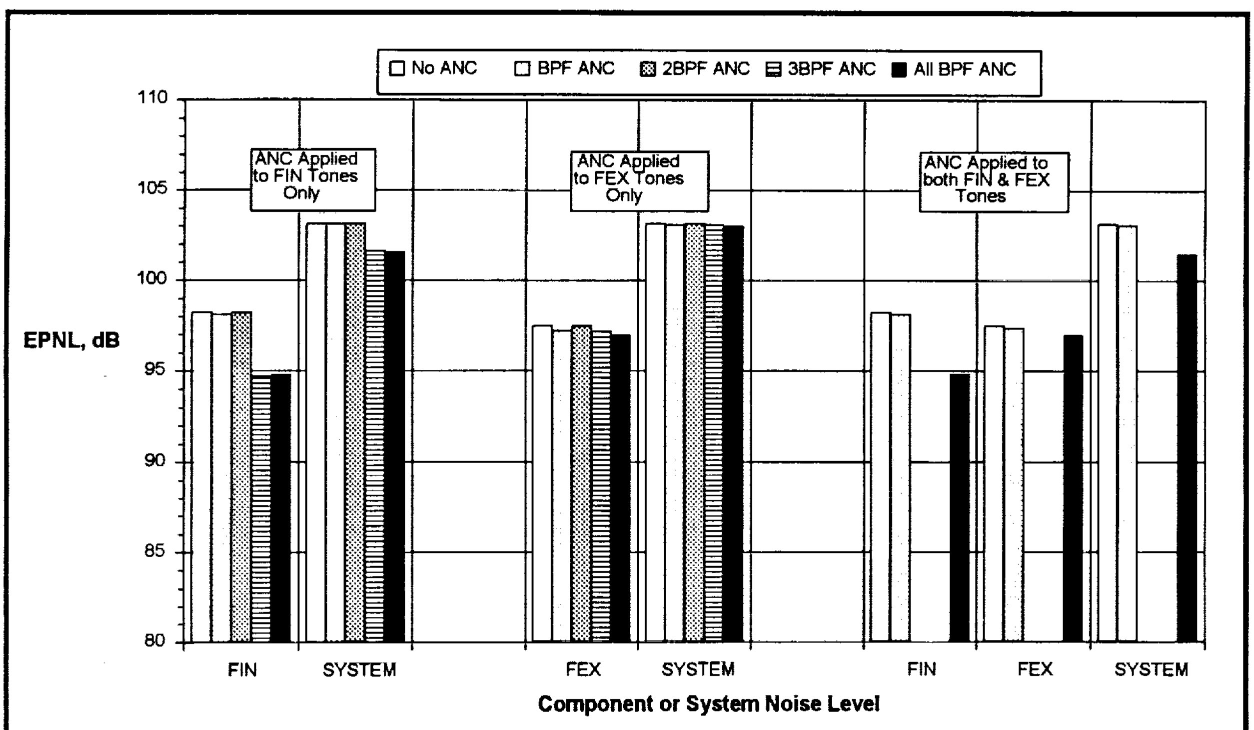

Figure 19. EPNL with and without ANC for components and system, S45 engine at approach.

Several important trends can be noted. From Table 8, it can be observed that for the S75 engine, ANC provided about 6 dB suppression in the inlet and 3 dB suppression in the exhaust at sideline and cutback. The overall suppression is controlled by the exhaust levels, which can be seen to be dominant in Tables 10 and 11. Thus, the dominance of exhaust noise and the relatively lower tone protrusion in the exhaust provides the limiting factor on the overall benefit achievable from ANC for the S75 engine at sideline and cutback. Overall suppression is 2.5 EPNdB at sideline and 2.7 EPNdB at cutback.

Examination of the tone-removal benefits for the S45 engine in Table 9 indicates somewhat more balance between inlet and exhaust effects, compared to the S75 engine,when all harmonics are removed at sideline and cutback conditions. The S45 engine is also exhaust-noise-controlled at sideline and cutback, so that the overall benefit is limited by the exhaust suppression. Overall suppression is 3.1 EPNdB at sideline and 1.0 EPNdB at cutback.

At approach, both the S75 and the S45 engine are relatively balanced between inlet and exhaust fan noise contributions to EPNL (see Tables 12 and 15). The tone protrusions (from Tables 8 and 9), however, are relatively small, and greater in the inlet than the exhaust. Overall suppression is only 1.0 EPNdB for the S75 engine and 1.7 EPNdB for the S45 engine.

4.5.2. Partial Reduction of Tones

In the previous results, the tone removal was accomplished by identifying the maximum protrusions of the BPF, 2BPF, and 3BPF tones and applying the active noise control procedure at all angles to the extent of this maximum ΔdB protrusion. Two cases were reexamined by applying the procedure of tone removal in multiple steps to determine the extent of the benefit with different amounts of applied suppression.

The test cases for this study were the S75 sideline with multiple steps applied to the exhaust BPF and the S45 sideline case with multiple steps applied to the exhaust 3BPF. The tone levels were reduced in steps of 25%, 50%, 75%, and 100% of the maximum protrusion. The effects of this stepwise suppression is shown in Figure 20. for the S75, case and Figure 21 for the S45 case. The data indicate that, relative to the benefit with full tone level reduction, a significant amount of ANC benefit is obtained with approximately 50% of the tone level reduction.

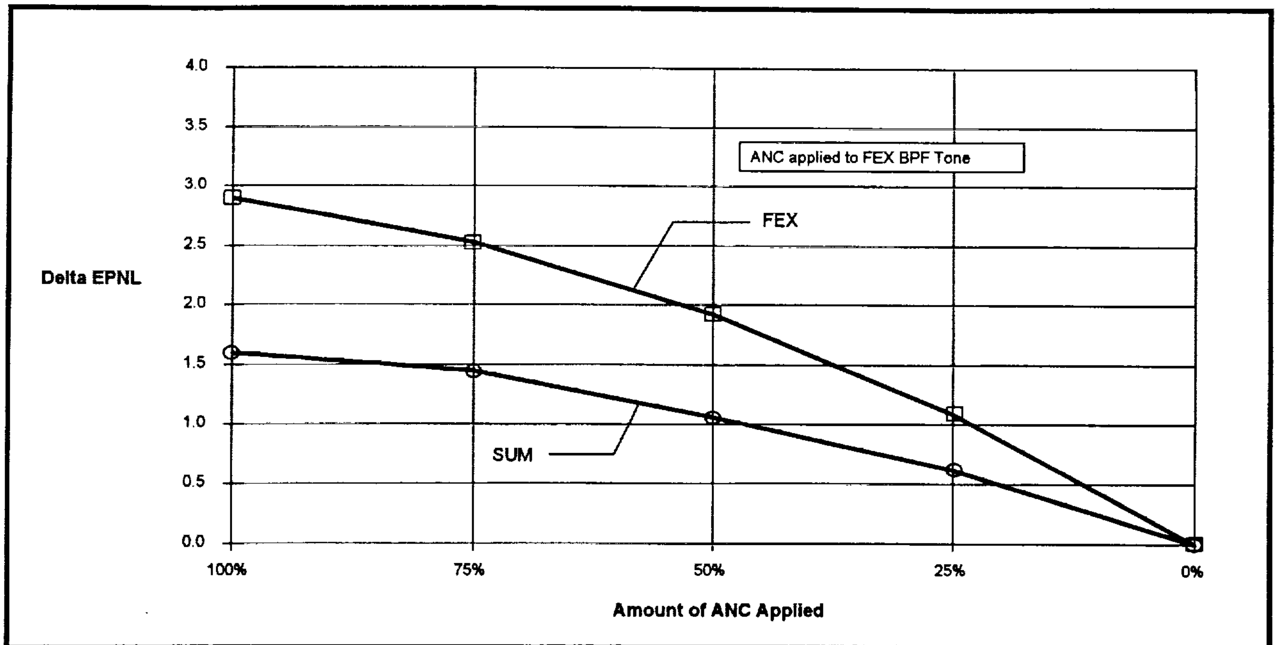

Figure 20. Variation in EPNL suppression for S75 engine at sideline as tone reduction is varied.

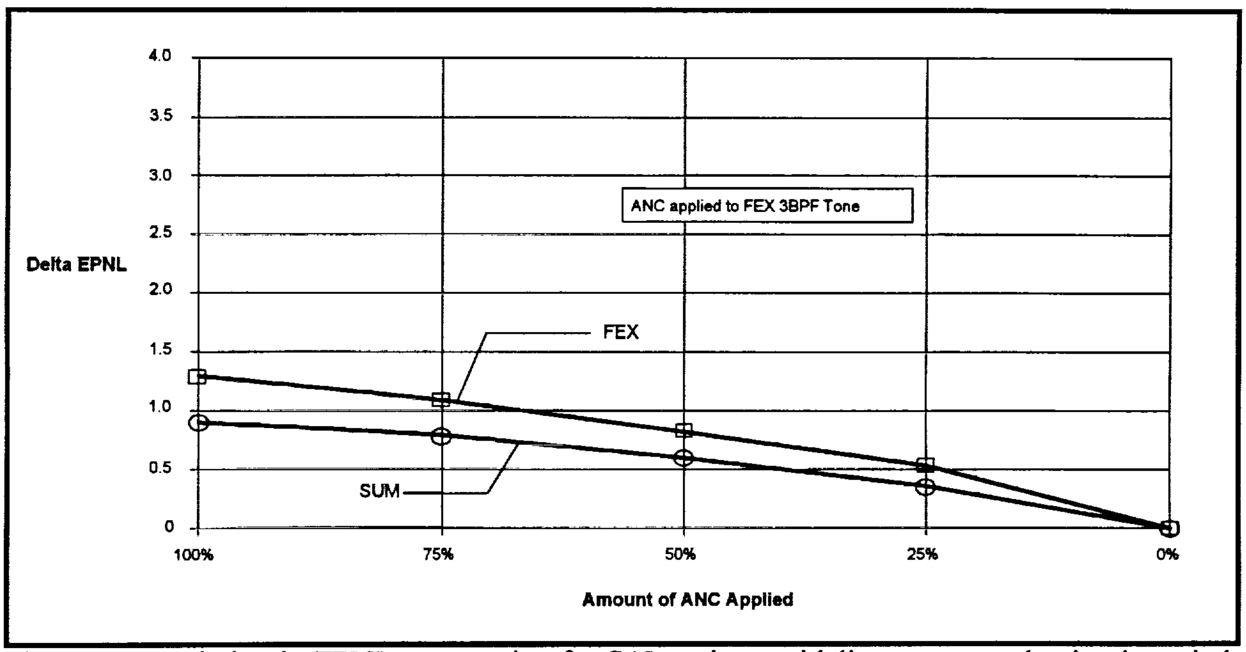

Figure 21. Variation in EPNL suppression for S45 engine at sideline as tone reduction is varied.

4.6. Summary of System Noise Study Conclusions

From examination of the data presented in the previous section, the major conclusions that can be drawn are that, for a fan pressure ratio of 1.75, ANC of tones gives about the same suppression as acoustic treatment without ANC, and for a fan pressure ratio of 1.45, ANC appears to offer reduced effectiveness. Additionally, ANC appears to be more effective at sideline and cutback conditions than at approach because the tone protrusion is significantly smaller at approach, and because the fan exhaust noise dominates at sideline and cutback without passive treatment.

4.6.1. Conclusions for Sideline and Cutback Conditions

For forward radiated noise, application of active noise control to the BPF tone results in significant reduction in the inlet-radiated noise component. However, this impact is limited to 0.6 EPNdB on the overall noise level, since the inlet radiated noise is not a major contributor to the overall noise at sideline or cutback conditions. ANC of the second and third harmonics of blade passing frequency have very little effect on component or overall noise level, due to their small participation.

For aft-radiated noise, application of ANC to the BPF tone of the S75 engine resulted in 2.5 to 3.0 EPNdB benefit in the fan exhaust component and 1.5 EPNdB benefit in the overall EPNL. There was again no benefit with application of ANC to the 2BPF and 3BPF. For the S45 engine, there was less than 1 EPNdB benefit from application of ANC to the 2BPF and 3BPF.

Application of ANC to the BPF tone of both forward- and aft-radiated fan noise of the S75 engine resulted in 2 EPNdB reduction in the overall EPNL at both sideline and cutback. Similar application to the S45 engine resulted in less than a 1 EPNdB benefit in overall EPNL.

The benefits obtained at sideline and cutback with the application of active noise control to the hardwall engine levels of the S75 and the S45 engines are almost equal to the benefits of applying acoustic treatment. For the S45 engine, while the two benefits are equal at sideline, the treatment is more beneficial at cutback than application of active noise control (see Tables 8 and 9.

Directivity plots of inlet radiated noise and exhaust radiated noise for the S45 engine are presented in Figures 22. and 23., respectively, at sideline condition. These plots compare the directivities of hardwall, hardwall with active noise control, and treated configurations.

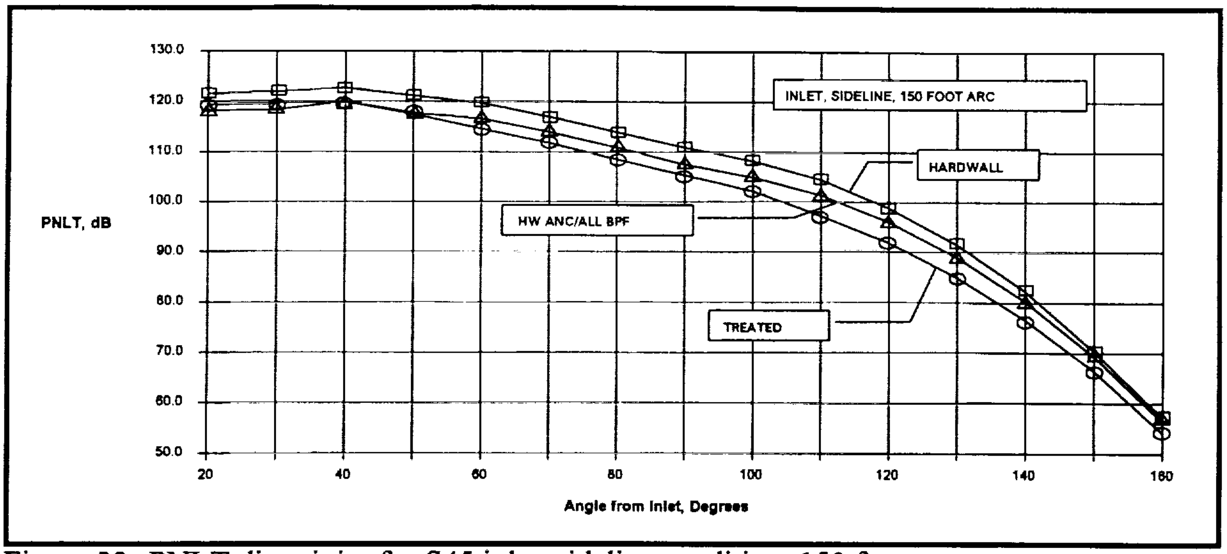

Figure 22. PNLT directivity for S45 inlet, sideline condition, 150 foot arc.

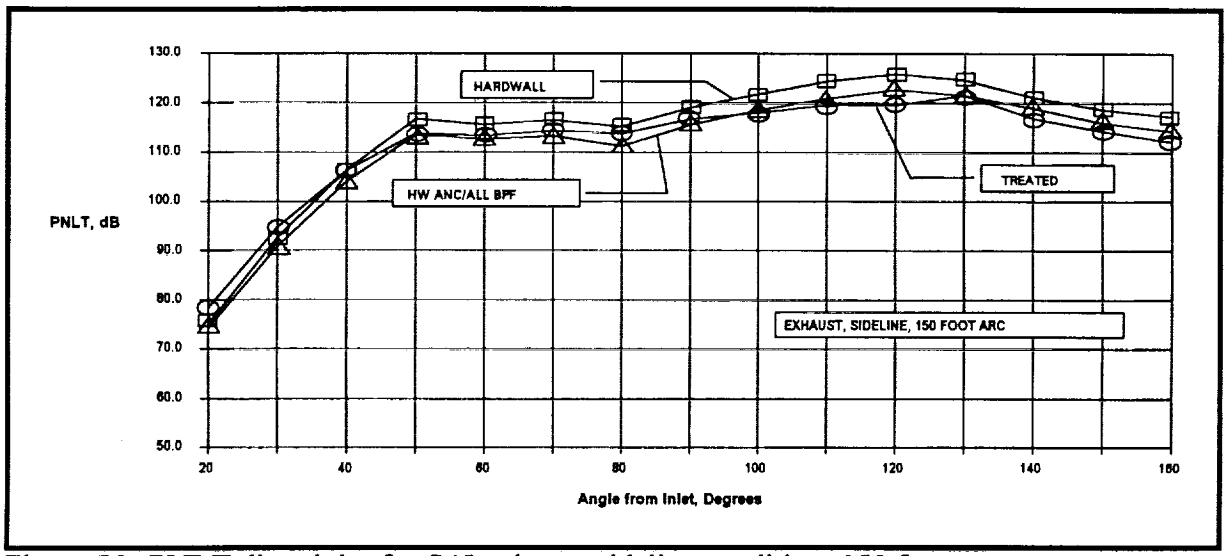

Figure 23. PNLT directivity for S45 exhaust, sideline condition, 150 foot arc.

Since treatment works on both reducing tones and on reducing broadband levels, more benefit is noticed with the treated configurations. However, there may be remaining tonal protrusion in the treated engine case, such that additional benefit may be gained by applying ANC to the treated engine.

An indication of the possibilities can be seen in Figure 24, which shows a spectral plot of Sound Pressure Level radiated by the S45 engine at 40 degrees to the inlet on a 150 foot arc, comparing the hardwall engine, the hardwall engine with tones removed, and the treated engine. Note that the tones, for this case, still contribute to the spectra suppressed by treatment.

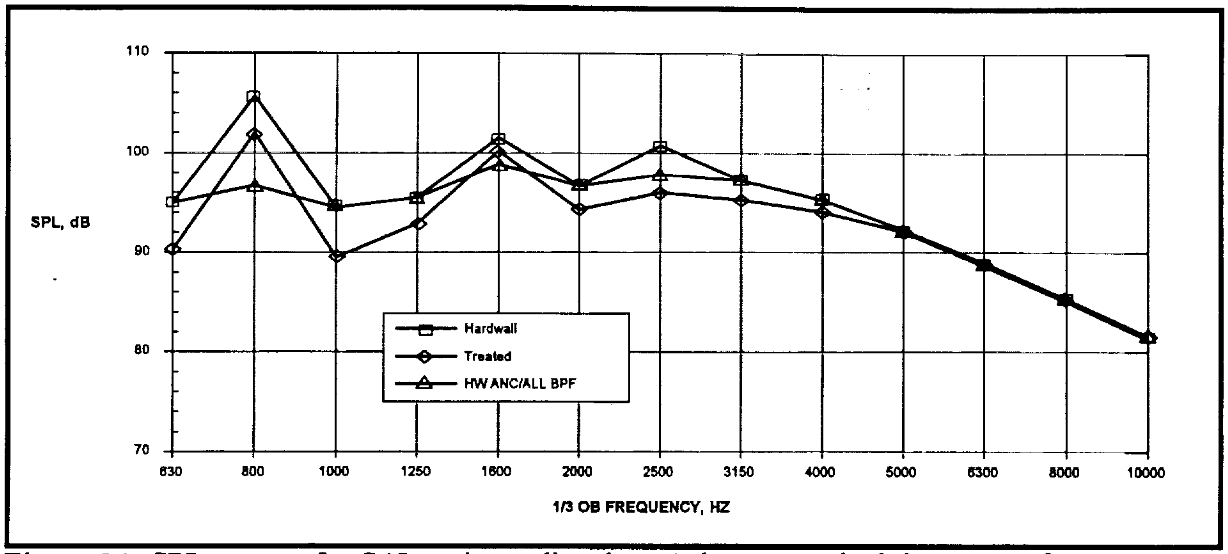

Figure 24. SPL spectra for S45 engine radiated at 40 degrees to the inlet on 150 foot arc.

4.6.2. Conclusions for Approach Conditions

At approach conditions, the benefits of ANC for the cases considered was less than for the sideline or cutback conditions. The largest component effects at approach were a reduction of 1.5 EPNdB for the BPF tone in the S75 inlet and a reduction of 3.5 EPNdB for the 3BPF tone in the S45 inlet. All exhaust reductions were below 1 EPNdB, even for all tones removed. Overall suppressions obtained were 1.0 EPNdB for the S75 engine and 1.7 EPNdB for the S45 engine. This compares to treatment suppressions of 3.9 EPNdB and 3.4 EPNdB for the S75 and S45 engines, respectively.

4.7. Economic Impact of ANC System Installation

Adding active noise control systems to the engines on an aircraft will add weight, manufacturing cost, and maintenance cost to the operation of the aircraft. These additions will have, an impact on aircraft Direct Operating Cost (DOC). Studies of the impacts of engine design on DOC were conducted in Reference 12. A similar procedure was followed here to estimate the impact of installing an ANC system on the inlet of each of the engines on the aircraft DOC.

It is assumed that the only effect of adding an ANC system on the design of the engine will be a displacement of the acoustic treatment panel to accommodate the ANC. One row of transducers will be added to the inlet duct. Such design changes as decreasing the rotor/stator spacing to increase the tone generation while decreasing engine weight will not be considered here, as this would change the source. Such considerations might, however, be appropriate for total integration of the ANC system.

The results of Reference 12 have been simplified by using multiple linear regression techniques to develop a linear relationship for percent increase in DOC relative to the baseline E^3 engine design. The relationship, which applies to the S30, S45, S60, and S75 engines used in this study (and only to these engines), is given by

$$\%\Delta DOC \approx 0.3989(\%\Delta FB) + 0.0847(\%\Delta MFGC) + 0.0758(\%\Delta MTC)$$

where %ΔDOC = percent change in Direct Operating Cost
%ΔMFGC = percent change in manufacturing cost
%ΔMTC = percent change in maintenence cost

and %ΔFB is percent change in fuel burn, which is in turn given by

$$\%\Delta FB \approx 1.255(\%\Delta SFC) + 0.1349(\%\Delta WT) + 0.0517(\%\Delta D)$$

where %ΔSFC = percent change in specific fuel consumption
%ΔWT = percent change in engine weight
%ΔD = percent change in nacelle drag

It will be assumed that the installation of the ANC system has no direct effect on specific fuel consumption (the engine cycle is not changed) and no effect on drag (the outer nacelle lines are assumed to be unchanged). Thus, the only effect on fuel burn will be through the added weight of the ANC system. The equation for %ΔFB is based on a fuel price of $1.00 per gallon, so a factor must be applied for different fuel costs.

First, it is necessary to estimate the weight of the ANC system and subtract the weight of the acoustic treatment panel that it displaces. The transducer hardware is assumed to be made of 40 ANC elements 6 inches by 6 inches, spaced equally around the periphery of the inlet duct, and constructed of aluminum. The fixed weight, consisting of transducer elements, stringers between the elements, back pressure tubing and control valving, electrical wiring, and electronics, is estimated to weigh 205 lbs. The variable weight parts, which depend on duct radius, consists of an aluminum faceplate and section support rings. The weight of a single-degree-of-freedom aluminum honeycomb treatment panel 6 inches long is subtracted from the weight of the ANC system. Table 16 provides weight estimates for the four engine cases. The percent increase in fuel burn is based on fuel cost of $1.00/gal.

Table 16. Added weight estimate for ANC system for four engine cases.

Engine FPR	Engine Weight, lbs	ANC Extra Weight, lbs	% Increase in Weight	% Increase in Fuel Burn
1.30	17398	211.3	1.21	0.163
1.45	13530	210.2	1.55	0.209
1.60	12630	209.7	1.66	0.224
1.75	11210	209.4	1.87	0.252

The cost of manufacturing of the ANC system, including electronics, assuming assembly-line fabrication methods, is estimated to range between $100K and $250K as low and high estimates. The estimated maintenance cost for the ANC system, per aircraft shop visit, is a low value of $25K to a high value of $50K. Table 17 gives the estimated maximum and minimum values of percent increase in fuel burn, manufacturing cost, maintenance cost, and DOC for the four engine cases.

Table 17. Percent increase in operating cost due to installation of ANC systems for four engine cases.

Engine FPR	MFGC $K per engine	MTC $K per shp vist	%ΔFB Min $1/gal	%ΔFB Max $1.5/gal	%Δ MFGC Min	%Δ MFGC Mzx	%Δ MTC Min	%Δ MTC Max	%Δ DOC Min	%Δ DOC Max
1.3	6560	983	0.163	0.244	1.52	3.81	2.54	5.09	0.39	0.81
1.45	5439	972	0.209	0.314	1.84	4.60	2.57	5.14	0.43	0.90
1.6	5406	1296	0.224	0.336	1.85	4.62	1.93	3.86	0.39	0.82
1.75	5108	1368	0.252	0.378	1.96	4.89	1.83	3.65	0.40	0.84

Figure 25. shows the minimum and maximum estimated increases in DOC for the four engine cases in graphic format. Note that the minimum increases are associated with the low fan pressure ratio engines, which have advantages in percent increase in fuel burn and manufacturing cost, but not in maintenance cost.

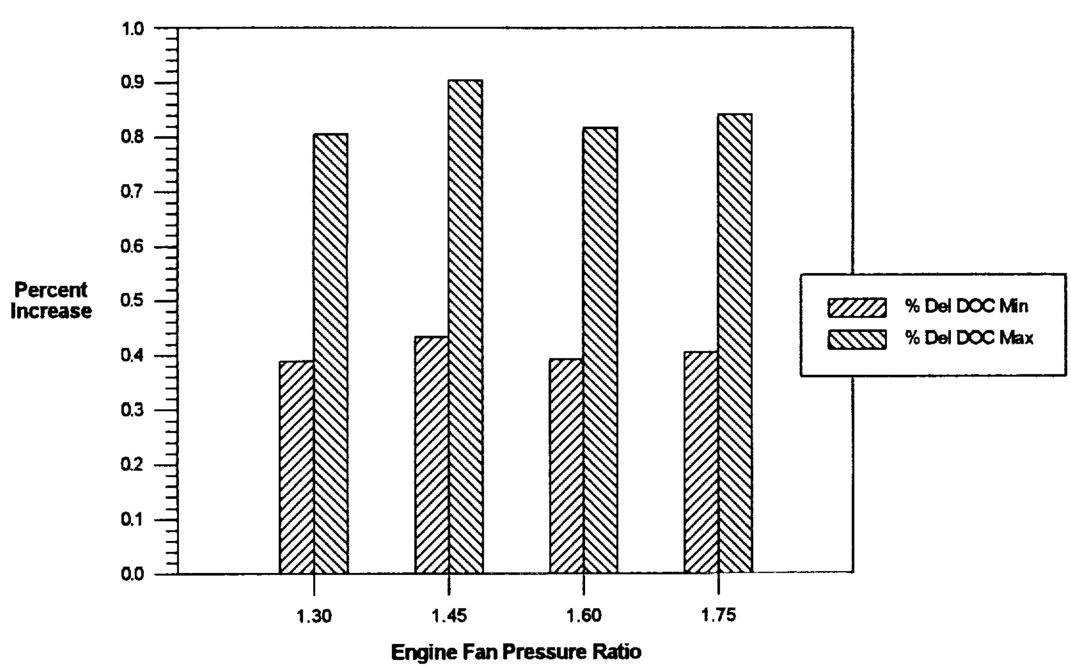

Figure 25. Comparison of minimum and maximum estimates of increases in DOC due to installation of ANC systems for four engine cases.

5. Recommendations for Further System Noise Studies

The study was limited to engines with fan pressure ratios of 1.45 and 1.75, although by assumption these results will apply closely to engines with 1.3 and 1.6 fan pressure ratios, as well. The results indicate that, for the engines considered, more ANC suppression can be obtained at sideline/takeoff/cutback conditions than at approach conditions.

Further study is needed to confirm the conclusions for engines with different pressure ratios, particularly the case for the lower 1.3 pressure ratio. Data is available to easily extend this study to the low pressure ratio case. The QCSEE (Quiet Clean Short Haul Experimental Engine) data, at a fan pressure ratio of 1.27, may be more representative of the low pressure ratio fan case than the E^3 engine, and should be included in future studies.

In-depth analyses of why the high engine speed cases give higher tonal suppression than the approach cases was not made as part of this study. Such an analysis, in terms of engine spectral and directivity pattern effects, is needed to understand more fully the behavior of the ANC tone removal, and to verify whether this is or is not a general trend, or simply an effect peculiar to the engine cases and/or databases chosen for study.

Further effort is needed to examine the potential of broadband ANC that would operate over selected frequency ranges and the design and effectiveness of hybrid ANC/passive treatment configurations. Studies of the potential of applying both ANC tone removal and treatment suppression, assuming some loss of treatment area to accommodate the ANC system, are recommended.

A useful study would be to examine the effects of an engine designed purposely to enhance the tonal spectrum, such as by reducing the vane/blade ratio and decreasing the rotor/stator spacing to produce stronger, lower spinning mode order tones. This would be useful only if there were a concurrent reduction in broadband levels, and if the ANC system could remove the higher level tones. The engine weight reduction afforded by such a redesign might increase the attractiveness of the ANC system.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
October 1994

3. REPORT TYPE AND DATES COVERED
Final Contractor Report

4. TITLE AND SUBTITLE
Active Control of Fan Noise-Feasibility Study
Volume 1: Flyover System Noise Studies

5. FUNDING NUMBERS
WU-538-03-11
C-NAS3-26617
Task Order 5

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8. PERFORMING ORGANIZATION REPORT NUMBER
E–9170

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135–3191

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA CR–195392

11. SUPPLEMENTARY NOTES
Project Manager, Laurence J. Heidelberg, Propulsion Systems Division, organization code 2770, NASA Lewis Research Center, (216) 433–3859.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Categories 07 and 71

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

A study has been completed to examine the potential reduction of aircraft flyover noise by the method of active noise control (ANC). It is assumed that the ANC system will be designed such that it cancels discrete tones radiating from the engine fan inlet or fan exhaust duct. Thus, without considering the engineering details of the ANC system design, tone levels are arbitrarily removed from the engine component noise spectrum and the flyover noise EPNL levels are compared with and without the presence of tones. The study was conducted for a range of engine cycles, corresponding to fan pressure ratios from 1.3 to 1.75. The major conclusions that can be drawn are that, for a fan pressure ratio of 1.75, ANC of tones gives about the same suppression as acoustic treatment without ANC, and for a fan pressure ratio of 1.45, ANC appears to offer less effectiveness than passive treatment. Additionally, ANC appears to be more effective at sideline and cutback conditions than at approach. Overall EPNL suppressions due to tone removal range from about 1 to 3 dB at takeoff engine speeds and from 1 to 1.5 dB at approach speeds. Studies of economic impact of the installation of an ANC system for the four engine cases indicate increases of DOC ranging from 1% to 2%, favoring the lower fan pressure ratio engines. Further study is needed to confirm the results by examining additional engine data, particularly at low fan pressure ratios, and studying the details of the current results to obtain a more complete understanding. Further studies should also include determining the effects of combining passive and active treatment.

14. SUBJECT TERMS
Aircraft flyover noise; Active noise control; Noise suppression

15. NUMBER OF PAGES
40

16. PRICE CODE
A03

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102